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Community Noise Impact of Advanced Aircraft Designs

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PREFACE

This report was prepared by McDonnell Douglas Aerospace under Task Assignment 17 of contract NAS1-20103 with NASA Langley Research Center. The Technical monitor at NASA for this task was Dr. Kevin P. Shepherd. The MDA Task Leader was Kevin Elmer. The members of the McDonnell Douglas team that participated in this task order and deserve recognition for their contributions are as follows:

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SYMBOLS AND ABBREVIATIONS

CASES	Computer Aided Sizing and Evaluation System
CG	Center of Gravity
$C_{L_{max}}$	Maximum lift coefficient
C_L	Lift coefficient
CPA	Closest point of approach
DFBR	Distance from brake release
DOC	Direct Operating Cost
EIS	Entry Into Service date
EIR	Environmental Impact Report
EPNL	Effective Perceived Noise Level
FAR	Federal Aviation Regulation
F_n	Engine net thrust
Fn/δ	Corrected net thrust
HBPR	High bypass ratio
ICA	Initial Cruise Altitude
ICAO	International Civil Aviation Organization
INM	Integrated Noise Model
IRAD	Independent Research and Development
L/D	Aerodynamic lift to drag ratio
Ldn	Day - night level
MAC	Mean aerodynamic cord
MTOGW	Maximum takeoff gross weight
NLP	Non-Linear Programming
NPD	Noise-power-distance table
OEW	Operating Empty Weight
OTIS	Optimal Trajectory by Implicit Simulation
ROC	Rate of Climb
SEL	Sound Exposure Level
SFC	(Engine) Specific Fuel Consumption
S_W	Wing area
TOFL	Takeoff Field Length
VD	Maximum speeds in a dive
VHBPR	Very high bypass ratio

V_{cal}	Calibrated aircraft speed
V_{min}	Minimum aircraft speed
WMPL	Maximum payload
WPPL	Performance payload
V_{true}	True airspeed
α	Aircraft Angle of Attack
γ	Climb angle
δ_F	Flap deflection angle

1. INTRODUCTION

Previous analysis of advanced aircraft designs (see Reference 1) has shown that a modest amount of noise reduction is attainable by inclusion of advanced high lift systems. This was demonstrated for short-to-medium range and medium-to-long range aircraft designs. It was also found that the design techniques which reduce noise further, such as oversizing the wing to reduce the takeoff thrust requirement, and reducing the approach flap setting maximizes the noise benefit of advanced high lift systems without a significant performance or aircraft weight penalty. These design techniques may also be applied to the conventional high lift wing, with noise improvements of lesser magnitude. The objective of this follow-on study is to assess the noise benefit advanced aircraft design yields for communities both close to and further away from airports.

In the past aircraft operators were subjected to a variety of noise restrictions established by local authorities of "noise sensitive airports", such restrictions included noise limits at specific locations and total community exposure area limits. These restrictions resulted in aircraft type noise classifications, curfews and slot allocation schemes intended to reduce community noise impact. Operators, as a consequence of these regulations, developed customized flight procedures for individual airports in order to minimize the impact on their operations. This practice was somewhat restricted when the FAA standardized noise abatement takeoff procedures by recommending two certified procedures per aircraft type, a "close in " and a "distant" community noise abatement procedure. "Close in" has been defined as areas within 5 nautical miles of the airport, "distant" is considered as 5 - 10 nautical miles. Communities beyond this were not considered since modern subsonic aircraft are not expected to cause disturbances this far from the airport except for perhaps operations during late night hours and in remote areas where background noise levels are very low.

In the present study two flight procedures, one for close in communities and one for distant communities, were defined for both class of aircraft designs of the previous study and evaluated at specific airports for their effectiveness at reducing community noise.

Analysis of the impact on overall operations at an airport was limited to older types of aircraft and more modern aircraft that currently have conventional high lift systems. It was recognized that operators will most likely choose to fly their quietest aircraft out of the most noise restrictive airports. And since the aircraft of this study with advanced high lift systems were sized for noise they will be the quietest aircraft.

The terms "conventional" and "advanced" used in this report and in the prior report (Reference 1) describe high lift systems where "Conventional" refers to systems which are simple, light-weight, low-cost, and require low maintenance. "Advanced" systems have a higher lift to drag (L/D) ratio, and are complex, heavier, and more costly.

Although FAA rules currently prevent variations in thrust and control surface configurations during takeoff, other than cutback, future advances in automated throttle and flight management systems could lead to certification of "black box" noise abatement procedures that continuously vary thrust and flight controls to reduce community noise.

For this reason a study of automated flight procedures was also conducted. Flight procedures were developed that were optimized in two different ways. The first was to optimize for performance while imposing aerodynamic and noise constraints along the flight path. The second approach, initiated in this study, was to minimize the contour area of noise exposure above a specified level.

All long term forecasts of passenger enplanements indicate that air traffic will continue to grow and the least costly way to accommodate the increase is to simply increase the daily operations at an airport. This increase in air traffic will drive the need to lower noise levels of individual aircraft so that more operations can be flown without changing the cumulative noise environment. In this study we also estimated the potential for increased traffic due to the operation of quieter aircraft.

2. AIRCRAFT DEFINITIONS

Aircraft configurations for short-to-medium range and medium-to-long range aircraft defined in Reference 1 were used for further community noise analysis in the present study.

The short-to-medium range aircraft is a two class, narrow body, 150 seat airplane design that can fly 2,500 nautical miles. This aircraft has an initial cruise altitude of 31,000 feet and a cruise Mach number of 0.78. Other design criteria used to size this aircraft included the takeoff field length no greater than 7,000 feet and the approach speed no greater than 130 knots.

The medium-to-long range aircraft is a three class, international seating (slightly increased seat pitch), 275 seat airplane design that can fly 6,000 nautical miles. This aircraft has an initial cruise altitude of 35,000 feet and a cruise Mach number of 0.83. By design the takeoff field was not to exceed 9,000 feet and the approach speed could not be greater than 140 knots.

In order to span the range of engines that will most likely be used on future aircraft, two distinctly different engine types were analyzed with each configuration. The engines defined in Reference 1 were a high bypass ratio (HBPR) turbofan engine and a very high bypass ratio (VHBPR) turbofan engine. These engines were analyzed on both the short-to-medium and the medium-to-long range configurations.

One conventional and one advanced high lift system configuration has been developed for each of the airplane configurations. A definition of the these systems and the estimates of their low speed aerodynamic characteristics are given below.

For the short-to-medium range aircraft the conventional high lift system consists of a full span leading edge slat and vane/flap. The slat has a single position for both takeoff and landing. The trailing edge vane is fixed relative to the flap; maximum flap setting is 40°. The advanced high lift system uses a slat that is sealed at takeoff and fully open at landing. The trailing edge system is a Fowler-motion flap in two spanwise segments. Inboard of the trailing edge break the flap is a two element (main / auxiliary) type with the auxiliary flap remaining stowed at takeoff. Outboard of the wing break the flap is a single element design. Additionally, the ailerons are drooped for takeoff and landing thereby providing a full span high lift system. The maximum flap setting is 35° and refers to the deflection of the inboard main flap. Figure 1 shows a comparison of the design features of the conventional and advanced high lift systems.

For the medium-to-long range aircraft the conventional high lift system uses a full span leading edge slat with a single deflected position. The trailing edge vane/flap uses a simple external hinge system and has a maximum flap setting of 50°. The advanced high lift system is basically the same as that for the short-to-medium range aircraft; a two position full span slat, Fowler-motion flaps, and drooped ailerons for takeoff and landing. The inboard flap has two elements; the auxiliary flap remains stowed at takeoff. The midspan and outboard flaps are both single element. The maximum flap setting is 30°. An auto slat system is assumed for this study which opens the slats from the takeoff (sealed) position to the landing position near stall to improve the takeoff stall speeds. Figure 2 shows a comparison of the conventional and advanced high lift system designs for the medium-to-long range aircraft.

The sizing procedure commonly used in preliminary aircraft design studies is to chose a combination of wing area (S_W) and thrust (F_n) which yields the least value of maximum takeoff gross weight (MTOGW) for the design mission. Reference 1, however, showed that the best way to implement a high lift systems in terms of noise versus performance trade-offs, is to select a larger S_W and lower F_n combination. Another design technique that becomes viable with "oversized" wings is to reduce the approach flap setting to as little as possible without exceeding the approach speed criteria. This combination of "oversized" wing and reduced approach flap setting maximizes the noise benefit afforded from the high lift systems in aircraft designs and will be referred to as "noise sizing".

A total of eight aircraft from Reference 1 were analyzed in the present study to determine the impact of "noise sizing" with advanced high lift systems on community noise. The four aircraft with conventional high lift systems were sized with a S_W and F_n combination that minimized MTOGW. The sizing criteria of the four aircraft with advanced high lift systems, however, was different. The S_W for these aircraft was set to that of their respective conventional high lift aircraft and then the F_n which provided the desired takeoff field length was chosen. This approach was selected to show the maximum noise benefit obtainable through sizing techniques to reduce noise and through the implementation of advanced high lift systems.

Table 1 gives a performance comparison of the four short-to-medium range aircraft. The "noise sized" aircraft with advanced high lift system are heavier than the corresponding "performance sized" aircraft with conventional high lift systems. This indicates that the weight penalty of the complex high lift system has a larger impact on the OEW (and MTOGW) than the reduction in engine size permitted by the improvement in low-speed L/D. Also, the VHBPR - powered aircraft are heavier and require higher thrust than the corresponding HBPR - powered aircraft. This is because the range is too short for the improved fuel efficiency of the VHBPR engine to offset it's higher weight and drag.

The effect on direct operating cost (DOC) of sizing for noise instead of performance was to reduce the 0.8% benefit of advanced high lift systems (see Reference 1) to 0.1% for the short-to-medium range aircraft. Figure 3 shows that this is due to the increase in ownership cost per trip having a greater impact on DOC than the decrease in cash cost per trip.

Table 2 shows the same performance comparison for the medium-to-long range aircraft. Results are similar to the short-to-medium range aircraft, in comparison of advanced to conventional high lift. Comparison by engine type shows the value of the higher bypass ration on a longer design mission. The VHBPR engine provides a lower MTOGW and requires less thrust in spite of a higher OEW than the HBPR engine.

Similar to the short-to-medium range aircraft, the benefit in DOC due to advanced high lift systems dropped from 0.2% to 0.0% for the medium-to-long range aircraft. Figure 4 shows that the increase in ownership cost per trip is offset by the decrease in cash cost per trip.

It should be noted that the "top down" DOC methods used in this analysis do not necessarily represent all of the costs associated with the complexity of the advanced high lift system.

3. FLIGHT PROCEDURES

Aircraft community noise is a function of both the operating condition of the aircraft and its proximity to the community. In order to regulate aircraft noise, the FAA has developed a means of classifying aircraft by their noise certification levels. Noise certification is defined by the noise measured on the ground at three specific locations relative to the flight path of an aircraft operating at the desired certification takeoff or landing gross weight. The three locations are commonly known as sideline, takeoff (cutback) and approach. The aircraft is flown according to a noise certification procedure which is specified in part 25 of the FAA certification guidelines. This procedure does not guarantee the lowest noise exposure for the community. It does however provide a means of comparing and ranking a variety of passenger aircraft in a given class based on their noise characteristics. The noise regulations for passenger aircraft have become increased in stringency throughout the years as expanding airports and surrounding communities have encroached on each other. Because of this problem, more emphasis has been placed on community noise and so ICAO has defined other noise abatement procedures that distinguish between different types of communities for noise relief. The implementation of new technology in thrust management and flight controls could lead to an even higher degree of specialization of flight procedures to reduce community noise.

3.1 Noise Certification

A certification flight procedure was first used to evaluate the eight aircraft of this study with regard to Stage 3 noise certification levels. The rule for Stage 3 noise limits is a function of only the aircraft takeoff gross weight and the number of engines on the aircraft. Figures 5, 6, and 7 are the certification rule curves for sideline, cutback, and approach noise respectively. The certification flight procedure requires takeoff power to be maintained until reaching an altitude of at least 984 feet (300 meters). The thrust is then reduced to that required to maintain level flight with one engine inoperative or to maintain a four percent climb gradient with both engines operating, which ever is greater. A flight path was generated for each aircraft for a certification flight procedure where the power was cutback at a distance from brake release of 17325 feet to the thrust required to maintain a climb gradient of four percent. The altitude where this power cutback occurred varied from 1364' to 1526' for the medium-to-long range aircraft and from 1604' to 1892' for the short-to-medium range aircraft, depending on the configuration. It was assumed that 4,000 feet prior to overflying the microphone was an adequate distance to avoid a noise intrusion from the full power portion of flight at the cutback microphone location (21325 feet from brake release). As soon as a calibrated airspeed of V_2+10 knots was attained it was held constant and the takeoff configuration selected was not changed (except for landing gear retraction) until reaching an altitude of 3,000 feet. Figure 8 illustrates the entire certification flight procedure.

3.2 Standard Noise Abatement

The FAA has developed a tool for conducting airport community noise studies based largely on the methodology described in Reference 2. The tool is called the Integrated Noise Method (INM) and has gained acceptance by airport authorities as a means of conducting Part 150 studies to evaluated the impact on community noise due to changes in airport operations. The INM was used in this study in part because of the large amount of performance and noise data available on nearly all existing passenger aircraft. The flight path data in the INM for any particular aircraft is given at a passenger load factor of 70 percent for several different operating ranges. Flight path data was therefore generated for each aircraft of the present study at a 70 percent load factor and several ranges.

3.3 Performance Optimization

Optimum performance is a major concern for the overall design of an aircraft. But since the major portion of flight is at the high altitude cruise condition, the impact of community noise constraints does not have a significant impact on the overall mission of the aircraft. Still, for operators who must fly out of noise sensitive airports, the cumulative effect of reduced performance can begin to impact operating costs. It would therefore be desirable to fly a takeoff procedure that satisfies the noise constraints provided by a standard noise abatement procedure but uses less fuel or more importantly requires less time to reach cruise altitude.

The MDC flight path optimization tool called OTIS (Optimal Trajectories by Implicit Simulation) described in Reference 3 was used to find the minimum time to climb and minimum fuel burn solutions for the two short-to-medium range aircraft with HBPR engines. The OTIS program satisfies boundary conditions by iterating differential equations through a combination of implicit integration and non-linear programming (NLP). The boundary conditions established for solving commercial aircraft trajectories are shown in Figure 9. First the initial condition of an aircraft was provided from the flight path data output of the CASES sizing program at an altitude of 500 feet to avoid having to build unnecessary complexity (takeoff analysis, gear retraction, ground effects, etc.) into the OTIS model. The fundamental assumptions were that automated flight management and throttle management systems would enable aircraft takeoff procedures to include flap and slat retraction as well as power reductions once the aircraft has climbed to an altitude of 500 feet. Aerodynamic constraints specified in FAA regulations such as stall margins, and minimum climb gradient for engine out conditions were modeled as well as other constraints like maximum pitch rate and rate of climb for passenger comfort, and maximum time at takeoff power for engine durability. A noise constraint was included that set limits on noise levels under the flight path beginning at the takeoff microphone location. The program was free to vary throttle, climb attitude, and the wing trailing edge flap and leading edge slat retractions, within the limitations of the control systems, from a starting altitude of 500 feet to a final altitude of 10,000 feet (flaps and slats fully retracted by 6,000 feet). The slat retraction, however had to occur after the flaps were fully retracted.

OTIS program structure requires the user to define several phases of flight so it can minimize or maximize an objective function. For the aircraft of this study seven phases of flight were defined and the objective function selected was minimum time of flight to reach an altitude of 10,000 feet. Table 3 lists the beginning point and an ending point of each of the seven phases. The beginning of a phase coincides with the end of the previous phase. At each phase constraints can be defined or changed. A phase can also be defined simply for modeling convenience. The start of phase 1 is the initial conditions specified as takeoff power (100% full throttle), optimum flap setting determined for an engine-out balanced field length condition and airspeed of V_2+10 knots. Here the aircraft is released from a fixed flap and throttle condition and OTIS is free to manage the aircraft flight controls for throttle, attitude, and flap setting. If the noise constraint is active the noise experienced at the first community microphone does not exceed the specified limit (95 EPNL). At phase 2 the flight controls are managed such that the community noise does not exceed the noise limit at the closest point of approach. The noise limit under the flight path was defined as having the level and fall-off rate typical of an existing Stage 3 aircraft of the same class. The takeoff model was terminated in phase 7 when the aircraft reached an altitude of 10,000 feet. Table 3 also shows the flight and noise (if invoked) constraints for each phase where a check mark indicates that the constraint was active.

4. AIRPORT OPERATIONS

Airport models for a typical large airport and a small noise sensitive airport were defined to show the impact of introducing noise sized aircraft with advanced high lift systems over a full range of typical airport operations. The data for these models was obtained from the latest Environmental Impact Reports for John Wayne airport and John F. Kennedy International airport.

4.1 Small / Medium Noise Sensitive Airport

John Wayne airport (SNA) in Orange County, California can always be found near the top of the list of the nation's most noise stringent airports. The recent amendment to the John Wayne airport access plan to comply with a new noise abatement flight procedure policy that was under FAA consideration, and the corresponding EIR (see Reference 4) made it an ideal source of data for the present study. Information on 1991 airport operations including aircraft mix, ground tracks, takeoff weights, and takeoff flight procedures were used to develop an airport model for the INM program. This model was then calibrated with the actual noise contour data found in Reference 4. It should be noted that the noise contours of the EIR were calculated from noise measurements averaged over the entire year. Table 4 shows the number of daily departures used in the model for the various aircraft and class. Class denotes noise rules that define maximum takeoff weights for a given aircraft type where A is less stringent than AA and E is the most restrictive. Data from the INM internal database was used which most closely matched each of these aircraft. Once the noise contours calculated from INM were calibrated against the EIS data, a model for projected operation in the year 2015 was developed. This model was again based on airport operations projections from the EIR for the year 2005. To project to the year 2015 the fleet mix was assumed to remain unchanged with an operations growth rate of 3% per year. The fleet mix and number of operations for 2015 are given in Table 5.

4.2 Large Capacity Airport

One of the largest international airports in the United States that has community noise concerns is New York's John F. Kennedy (JFK) International airport. The Port of New York Authority (PNYA) published an EIR for JFK which included data for airport operations in 1991. This data included fleet mix and runway usage. Additional information not included in the report was obtained from the PNYA directly. As was the case for the SNA model, INM data was used to model the aircraft operations at JFK. Table

6 shows the aircraft used to match the 1991 fleet mix described by the PNYA. The initial model included 43 aircraft. Because of the complexity of this model, a study to find an equivalent fleet mix with much fewer aircraft types was conducted. It was found that a fleet mix consisting of 6 aircraft, representative of each ICAO aircraft category, was sufficient to model all operations in 1991. A model of projected airport operations in the year 2015 was then made that assumed all Stage 2 aircraft were phased out and the number of operations grew at an average rate of 3% per year. A model of the 2015 operations at JFK is also shown in Table 6. The original model consisted of 26 aircraft types. Like in the 1991 model, a 6 aircraft model was found to be an adequate representation of the original model based on a noise contours comparison.

4.3 Introduction of Noise Sized Aircraft

Once baselines were established to represent airport operations in the year 2015 at a small / medium noise sensitive and a large capacity airport, an assessment of substituting operations with noise sized aircraft with advanced high lift systems was made. Of the four aircraft modeled in 2015 at SNA (Table 5), only one was assumed to already benefit from advanced high lift systems. Because the other three aircraft were assumed to be better represented by the performance sized aircraft with conventional high lift systems and HBPR engines, their operations were replaced with the noise sized 150 passenger aircraft with HBPR engines and an advanced high lift system. The change in community noise at SNA was then assessed. Of the six aircraft types in the 2015 model for JFK (Table 5), the three aircraft that can be considered performance sized aircraft were replaced with similar noise sized aircraft with advanced high lift systems. For both of these airports, the type of aircraft replaced were from two general ICAO categories, a category 2 aircraft and a category 5 aircraft. The category 2 aircraft is represented by the small-to-medium range aircraft of this study and the category 5 by the medium-to-long range aircraft. The change in performance due to advanced high lift systems on a future aircraft was defined as the difference in performance between the performance sized configuration with conventional high lift systems and the noise sized configuration with advanced high lift systems for each respective category of aircraft.

5. ANALYSIS AND RESULTS

5.1 Flight Performance Assessment

5.1.1 Certification Procedures

The flight path data that was generated using the noise certification procedure described in section 3.1 for the four short-to-medium range aircraft are shown in figure 10. The two configurations with advanced high lift systems have lower takeoff speeds than the corresponding configurations with conventional high lift systems. This permits a lower thrust to (aircraft) weight ratio (Fn/Wt), which results in lower thrust and altitude on the flight path. The reduced thrust requirement is, however a major benefit for noise reduction as will be discussed in later sections. The VHBPR powered configurations have higher MTOGW and higher thrust levels than the corresponding configurations with HBPR engines.

Noise certification flight path data for the four medium-to-long range aircraft are shown in figure 11. Once again the lower takeoff speed of advanced high lift systems cause a reduced takeoff thrust requirement which in turn reduces aircraft altitude. The VHBPR powered configurations for the medium-to-long range aircraft do show a significant improvement in performance over the HBPR engines (Table 2). The lower MTOGW permits a reduction in required thrust compared to the corresponding HBPR powered configurations.

5.1.2 Standard Noise Abatement Procedures

Two standard noise abatement flight paths for each of the short-to-medium range and medium-to-long range aircraft were generated following the ICAO recommended standard procedure for close in and distant communities. Figure 12 shows a comparison for the 150 passenger short-to-medium range aircraft at the design range of 2,500 nautical miles and a load factor of 70%. The flight procedures shown are: (a) a cutback at 800 feet or 1,000 feet for noise abatement in close communities and (b) a cutback at 1,500 feet for noise abatement in distant communities. Data for the configuration with a performance sized conventional high lift system is shown along with data for the one with a noise sized advanced high lift system. A comparison of the two indicates that the improvement in L/D due to the advanced high lift system has enabled the aircraft to takeoff at a lower speed. Because of the lower speed the thrust required is less. Figure 13 and 14 give similar comparisons for reduced missions of 1,500 and 500 nautical miles respectively. Figure 15 is included to show that as the range is reduced the takeoff field length and airspeed decrease, and the flight path altitude increases.

Figure 16 shows a comparison for the 275 passenger medium-to-long range aircraft at the design range of 6,000 nautical miles. The flight procedures shown here is the certification procedure of reducing power at a distance from brake release of 17325 feet. Data for both the conventional high lift system and advanced high lift system configurations are shown. A comparison of the two indicates that the improvement in L/D due to the advanced high lift system has enabled the aircraft to takeoff at a lower speed. Because of the lower speed the takeoff thrust required is less. Figure 17, 18, and 19 give similar comparisons for reduced missions of 4,500, 3,500 and 2,500 nautical miles respectively. Figure 20 is included to show that as the range is reduced the takeoff field length decreases. By comparing Figure 15 with Figure 20 it can be noticed that reducing range affects the medium-to-long range aircraft more dramatically than it does for the short-to-medium range aircraft. Figure 21 compares the takeoff roll distance for several flight paths of both the short-to-medium range and medium-to-long range aircraft. A reduction in payload from 100% to 70% caused the takeoff field length to decrease by an average of 28% for the short-to-medium range aircraft and by an average of 23% for the medium-to-long range aircraft. The further effect of reducing the range by 40% (from 2,500 NM to 1,500 NM or from 6,000 NM to 3,500 NM) caused the takeoff field length to decrease by an additional 12% for the short-to-medium range and by an additional 29% for the medium-to-long range aircraft. The larger reduction for the medium-to-long range aircraft is due to the fact that the corresponding fuel burned for the 40% range mission is a greater percentage of the total gross weight of the aircraft than for the short-to-medium range aircraft. The takeoff field length has a direct impact on the rest of the flight path and consequently the community noise. The shorter field length of the reduced payload and range causes the aircraft to be higher but flying slower over the community.

To see the benefit of advanced high lift systems, performance factors were calculated from the short-to-medium range and medium-to-long range aircraft data. Table 7 lists the factors for thrust, speed, and altitude for the 150 passenger and 275 passenger classes of aircraft at a 70% passenger load factor. Note that two sets of data are shown for the 150 passenger aircraft, a close-in community (cutback at 800 feet altitude) and a distance community (cutback at 1,500 feet altitude) noise abatement procedure. The thrust and speed factors are inversely proportional to the distance factors and the factors for the 275 passenger aircraft are, in general closer to unity than for the 150 passenger aircraft.

5.1.3 Optimized Flight Procedures

Optimized flight trajectory solutions for the short-to-medium range aircraft were generated using the OTIS program with minimum time to climb from an altitude of 500 feet to 10,000 feet as the objective function. The first set of results are for the aircraft which has a conventional high lift system and HBPR engines. The initial conditions are for a 2,500 NM mission with a 70% passenger payload. Figure 22 shows the altitude, flight path angle (γ), lift to drag ratio (L/D), and angle of attack (α) plotted against distance from brake release (DFBR). This flight path reached the constraint limit of $\gamma = 2.29^{o}$ (4% climb gradient limit) between 1.5 and 2.2 NM. The optimum solution was to immediately reduce the flight path angle, accelerate, and retract the flaps from the initial takeoff position (15^{o}) to fully retracted at 1.9 NM. The aircraft then flew with 0^{o} flap, slats extended until 5.3 NM. The slats were retracted with the specified retraction time of 8.8 seconds, between 5.3 NM and 5.9 NM. Linear interpolation was used between takeoff aero and cruise aero data sets because aerodynamic data was not available for modeling slat transition.

Figure 23 shows how noise (EPNL), corrected net thrust (Fn/δ), calibrated airspeed (Vcal), and rate of climb (ROC) vary with DFBR. The noise constraint (dashed curve), although not imposed is also shown. It can be noticed that the noise crosses this curve at distance of 3.7 NM. The maximum climb rate of 4,000 feet per minute (66.7 fps) was never reached. The engines were at full power (takeoff or climb) throughout this flight path to minimize time.

Referring back to Figure 22, the angle of attack shows an abrupt drop to 3 degrees followed by an abrupt recovery. This is believed to be an error in OTIS constraint application which was not resolved at the time of this report. This reflects in the L/D and may also affect the flight path angle and the climb rate (following chart).

The same mission was then flown with the noise constraint activated. Figure 24 shows that the minimum limit of $\gamma = 2.29^{o}$ (4% climb gradient limit) was only breifly reached at 3.7 NM. Flaps were fully retracted by 5.5 NM and slats were retracted by 7.4 NM.

Figure 25 shows that the noise limit of 95 EPNL at 10,000 feet (1.6 NM) DFBR was achieved and the fall-off noise constraint curve drove the flight path from that point until

6.6 NM where the noise level began to drop below the limit. Thrust was reduced to about 54% takeoff power and gradually increased to 100% at 6.6 NM. The transition from takeoff power to climb power (8.8 seconds) occurred between 6.4 NM and 6.9 NM. The climb rate limit (66.7 fps) was never reached.

Figure 26 shows the results for the short-to-medium range aircraft with an advanced high lift system and HBPR engines subjected to the same set of constraints (including noise) as the previous example. The minimum limit of $\gamma = 2.29^o$ (4% climb gradient limit) was again reached breifly at 4.0 NM. Flaps were fully retracted at 5.0 NM and slats were retracted at 7.5 NM.

Figure 27 shows the noise limit of 95 EPNL at 1.6 NM was reached and the fall-off noise constraint curve drove the flight path for this aircraft from that point until 5.5 NM where the noise level began to drop below the limit. The climb rate limit (66.7 fps) was not reached. The transition from takeoff power to climb power occurred at 7.0 NM.

The objective function, minimum time to reach 10,000 feet, was 225 seconds for the aircraft with a conventional high lift system without a noise constraint imposed. This was extended to 277 seconds when the noise constraint was activated. The aircraft with the advanced high lift system required 291 seconds to reach 10,000 feet with noise constraints invoked. This longer time is attributed to the fact that this aircraft is sized to a lower thrust. The minimum throttle required to meet the noise constraint was, however, less severe (59% vs. 54%) and sustained over a shorter duration than that of the aircraft with a conventional high lift system.

5.2 Single Event Noise Assessment

5.2.1 Standard Flight Procedures

Single event noise contours (noise due to a single takeoff and a single landing of one aircraft) were generated for all eight aircraft at the design MTOGW and range. Single event noise contours were also generated for all of the 70% payload flight paths at the maximum and reduced ranges discussed in section 5.1. Table 8 shows how the noise certification levels and several EPNL and SEL contour areas compare for the four short-to-medium range aircraft. The advanced high lift system has a larger benefit for the HBPR powered aircraft than for the VHBPR powered aircraft where the 85 EPNL contour area shows a reduction of 24% and 6% respectively. Table 9 shows a similar trend for the medium-to-long range aircraft with the 85 EPNL contour area reduced by 10% for the HBPR powered configurations and by 4% for the VHBPR powered configurations for the advanced high lift to conventional high lift comparisons.

The noise levels at certification locations along with EPNL and SEL contour areas are compared in Table 10 for the short-to-medium range aircraft with HBPR engines with conventional and advanced high lift systems for 70% passenger payload factors. Results for three ranges, 5,00, 1,500, and 2,500 nautical mile missions are shown. This data shows that as aircraft range is reduced, the benefits of noise sized aircraft with advanced high lift systems become more pronounced. With a close-in noise reduction procedure (thrust cutback at an altitude of 800 feet), for example the 85 EPNL contour area reduction changes from 22% to 30% when the aircraft range is reduced from 2,500 to 500 nautical miles.

To assess the impact of replacing operations existing in 2015 with new noise sized aircraft which benefit from improved L/D due to advanced high lift systems, the performance factors of Table 7 were applied to flight path data of aircraft in the 2015 airport models (short-to-medium range aircraft factors to MD-90 and medium-to-long range aircraft factors to MD-11 and 747). A comparison of noise certification levels and contour areas are shown in Table 11 for these six aircraft. The benefit in terms of ΔEPNdB at certification points and percent area change for EPNL and SEL contour areas are also given for the aircraft with improved L/D compared to their respective baselines. For a short-to-medium range aircraft (MD-90) the 85 EPNL contour area was reduced by 25%. For the medium-to-long range aircraft (MD-11 and 747) the corresponding contour area change was less (14% and 15%).

5.2.2 Optimized Flight Procedures

Single event noise contours were generated for each of the OTIS solutions discussed in section 5.1.3. Figure 28 shows the resultant 85 EPNL contour for the short-to-medium range aircraft with conventional high lift system and HBPR engines without an imposed noise constraint. The portion of the contour shown is only the takeoff after the initial condition (aircraft altitude is 500 feet) used in the OTIS model. The contour width decreases to 3 NM due to rapid acceleration. After 3 NM the contour width stays fairly constant as the trade between altitude gain and net thrust gain balanced. Finally at 4 NM the continued altitude gain becomes the dominate factor and the contour width begins to decrease. The closure point is reached at 5.8 NM.

Figure 29 shows the resultant 85 EPNL contour for this same aircraft but with an imposed noise constraint. The contour initially increased in width to a sideline distance of 3500 feet. It then quickly reduced when the throttle is cut back to meet the initial noise constraint at 1.6 NM. The contour width then grows less rapidly as the throttle is gradually restored to 90% at 5.5 NM. The contour width then drops off due to altitude gain. The closure point is reached at 6.8 NM.

Figure 30 shows the resultant 85 EPNL contour for the short-to-medium range aircraft with an advanced high lift system and HBPR engines with an imposed noise constraint. The maximum sideline distance of the contour was 2900 feet. The power cutback again caused this distance to drop to 2000 feet. After the throttle was ramped up to 100% at 5.5 NM there was no further fattening of the contour. The closure point is reached at 7.9 NM. The overall contour area for this aircraft is less than that for the aircraft with a conventional high lift system subjected to the same noise constraint.

5.3 Cumulative Noise Impact

Ldn noise contour areas were calculated for both the small / medium and the large capacity airports for years 1991, 2005, and 2015 and are shown in Table 12 and Table 13, respectively. The contour area for 65 Ldn is reduced by 10.8% in 2015 as a result of implementing noise sized aircraft with advanced high lift systems at the small / medium airport. At the large airport, however, the 65 Ldn contour area reduced by 15%. Contours for the small / medium noise sensitive airport model were also made for the current (1995) year. Figure 31 compares areas with Ldn noise exposures greater than 65 dB for these years. The change in slope of the curve before and after 2005 are due to the phase out of noisy stage 3 aircraft. The increase in area between 2005 and 2015 is due solely to the increase in operations that represent a 3% per year growth. When all aircraft have the performance benefit of advanced high lift systems the contour area drops by 3.9% from 1.02 to 0.98 square miles.

Figure 32 shows the 65 Ldn contour areas for the large airport. A reduction of 12% in contour area between 1991 and 2005 is due to the phase out of all the noisier Stage 2 certified aircraft. The total number of operations has grown at a rate of 3% per year from 351 operations in 1991 to 536 and 721 in years 2005 and 2015, respectively. After 2005 the fleet mix was assumed the same.

6. CONCLUSIONS AND RECOMMENDATIONS

The results of this task have shown that a modest noise benefit can be realized through "noise sizing" with advanced high lift systems. Single event contour areas were reduced by as much as 25% for short-to-medium range aircraft and by as much as 15% for medium-to-long range aircraft when standard noise abatement flight procedures are followed. Furthermore, the potential for growth in airport operations due to noise sized aircraft with advanced high lift systems was 10% for a small noise sensitive airport and 20% for a large capacity airport.

The OTIS optimization program was used to show that the noise reduction benefit of new aircraft can be maximized by implementing automated flight management and thrust management systems in an aircraft. Additional contour area reduction was obtained for the small-to-medium range aircraft with HBPR engines.

As growth in airport operations continue to clash with growing airport communities more emphasis will be placed on reducing the size of the noise footprint in the community. Recent modifications to the OTIS program supported by MDC under IRAD funds has included the capability to set noise contour area as the objective function to minimize. The solution process for a fixed node (beginning and ending points of a phase) structure is as follows:

- States, controls, and control rates are defined at every node
- Placards (Constraints) are calculated at every node and at the midpoint of every node
- Collocation equations are defined at all midpoints between nodes
- The sideline distance is calculated for a fixed dB noise level at all nodes and midpoints
- Fixed dB contour area is calculated by summing the trapezoids defined by drawing a straight line between the sideline distances at all nodes and midpoints
- The NLP problem is solved with the objective function equal to contour area and the states, controls, control rates at every node as independent variables as well as phase times

It should be noted that the gradient of the objective function is computed everywhere for all variables. This method is in the process of being validated and will soon be available to find minimum contour area solutions for the aircraft of this study.

With the takeoff noise contributing less to the total noise contour area, the emphasis on reducing community noise will shift towards approach noise. Through the incorporation of advanced high lift systems, automated flight management and thrust management systems approach flight procedures could also be optimized for noise.

REFERENCES

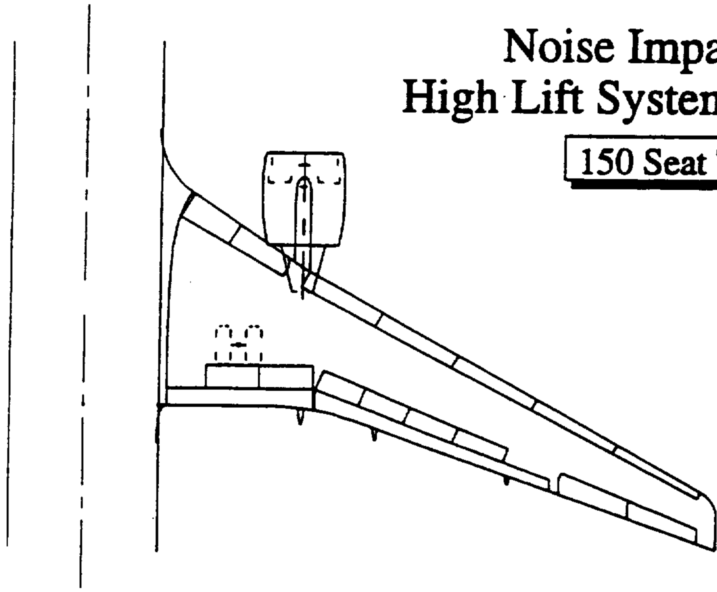
[1] Elmer and Joshi , "Noise Impact of Advanced High Lift Systems," NASA Contract Report #195028, March 1995.

[2] SAE Committee A-21, "Procedure for the Calculation of Airplane Noise in the Vicinity of Airports," Society of Automotive Engineering Aerospace Information Report 1845, March 1986.

[3] Flight Dynamics Directorate - Wright Lab Airforce System Command,"Optimal Trajectory by Implicit Simulation," WRDC-TR-90-3056, vol 1 - 5, December, 1990.

[4] County of Orange, "Amendments to the John Wayne Airport Phase 2 Access Plan Increasing Certain Maximum Permitted Noise Levels and the Addition of Certain New Regulatory Noise Monitoring Stations," Final Environmental Impact Report #546, June 9,1993.

[5] Federal Aviation Regulation Part 121, subpart R, paragraph 121.480, "Flight Time Limitations".



Noise Impact Study
High Lift System Definitions

150 Seat Twin

Ref. Quant. from 3-view J147958:

Sref = 1099.44 sq. ft.
AR = 11.0
Taper ratio = 0.275
c/4 sweep = 27.0°

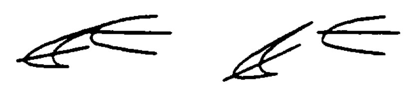
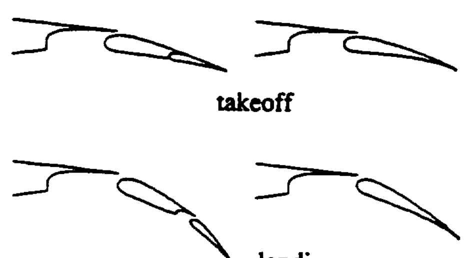
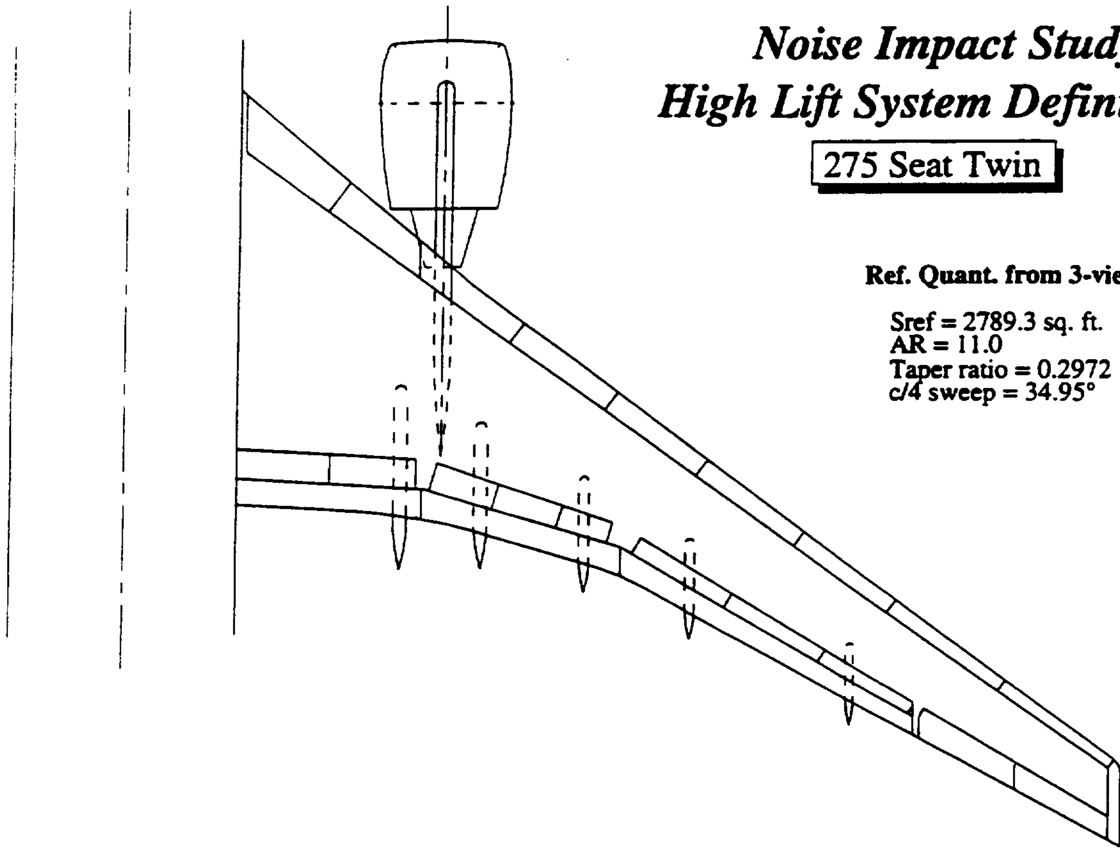
	Conventional High Lift System	**Advanced High Lift System**
Leading edge device	**Single position slat**  (takeoff & landing)	**Two position slat**  takeoff (sealed) landing
Trailing edge device	**vane/flap**  landing	**Fowler motion** 2-seg inbd / 1-seg outbd  takeoff landing
Additional features		**Drooped ailerons**

Figure 1. - 150 Passenger Aircraft High Lift Systems Comparison



Noise Impact Study
High Lift System Definitions
275 Seat Twin

Ref. Quant. from 3-view J147960:

Sref = 2789.3 sq. ft.
AR = 11.0
Taper ratio = 0.2972
c/4 sweep = 34.95°

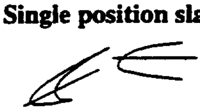
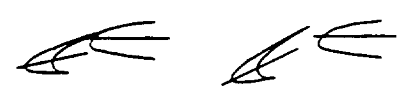
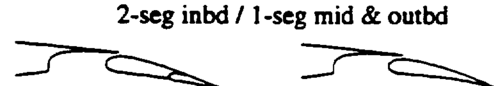
	Conventional High Lift System	**Advanced High Lift System**
Leading edge device	**Single position slat**  (takeoff & landing)	**Two position slat**  takeoff (sealed) landing
Trailing edge device	**vane/flap**  takeoff  landing	**Fowler motion flap** 2-seg inbd / 1-seg mid & outbd  takeoff  landing
Additional features		**Drooped ailerons for takeoff & landing**

Figure 2. - 275 Passenger Aircraft High Lift Systems Comparison

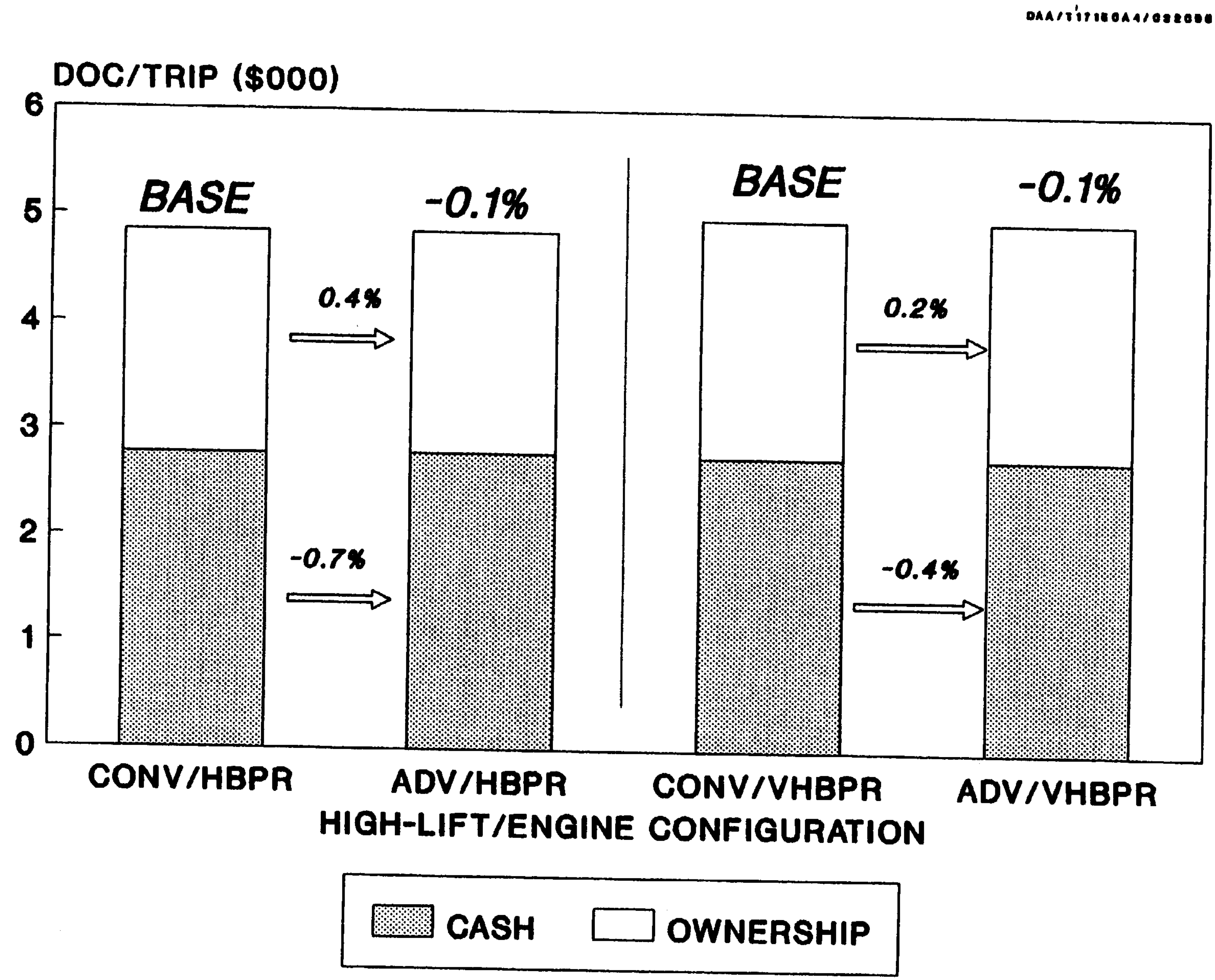


Figure 3. DOC Comparison For Short-To-Medium Range Aircraft

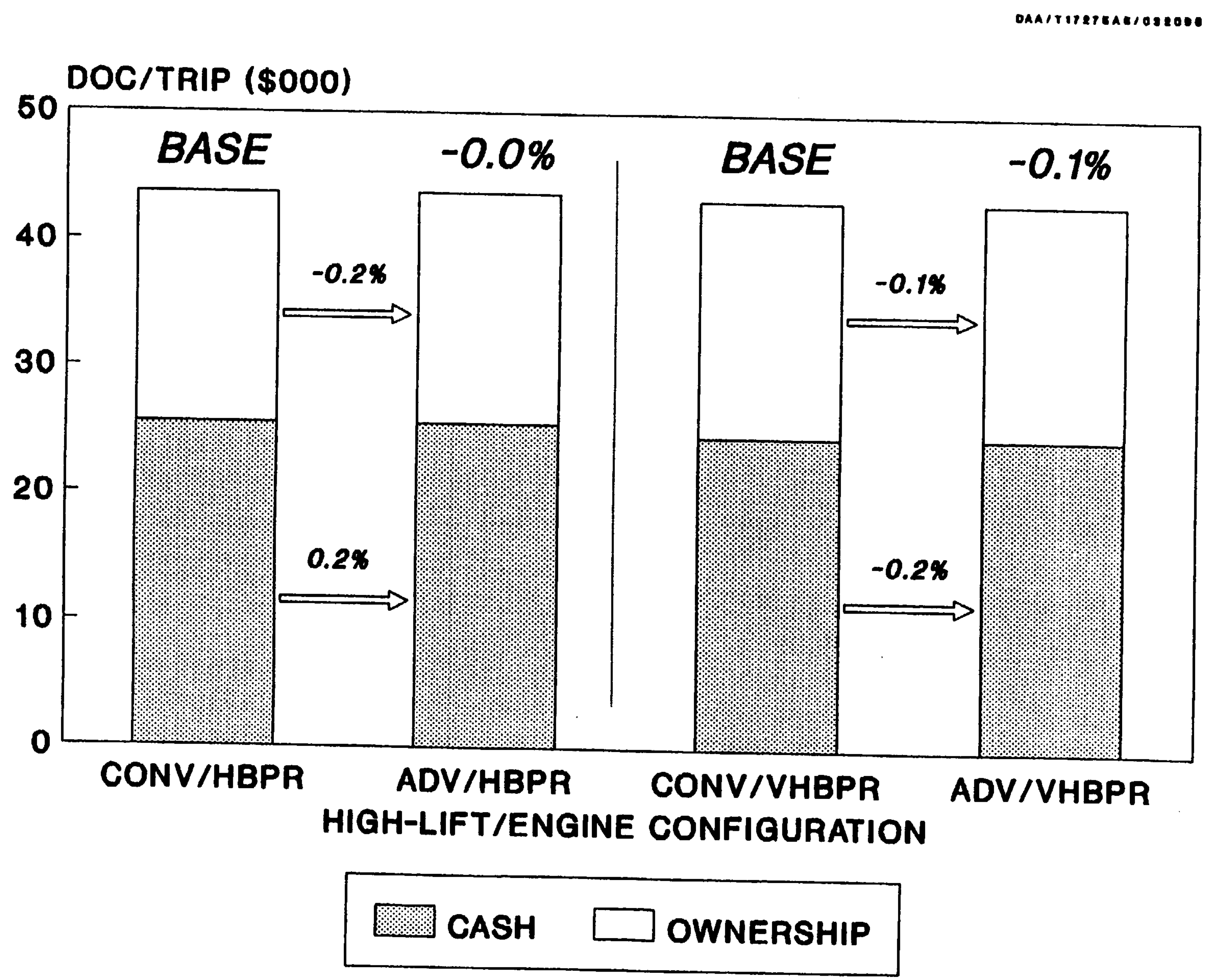


Figure 4. DOC Comparison For Medium-To-Long Range Aircraft

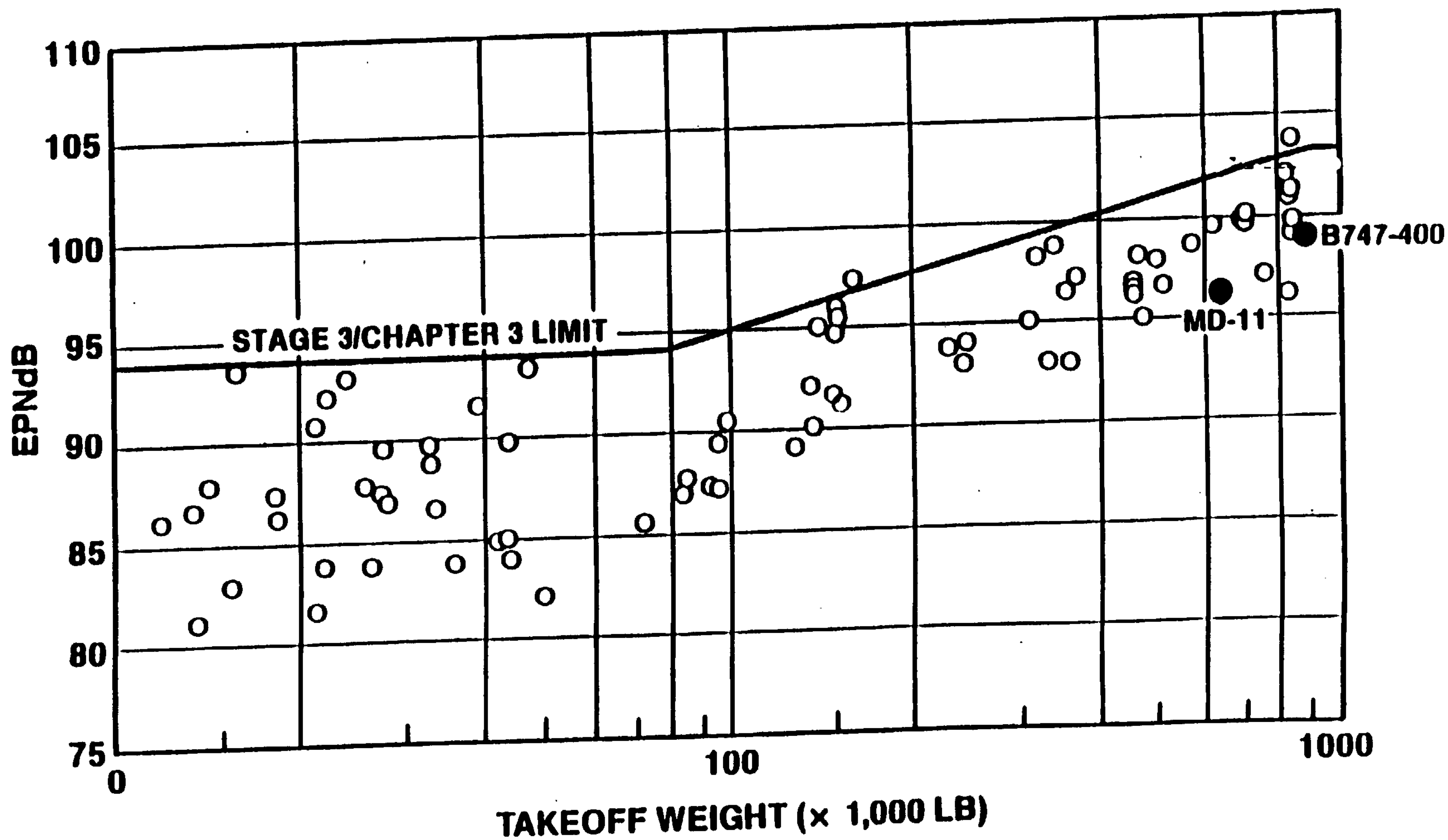


Figure 5. - FAR 36 Stage 3 Sideline Noise Limits

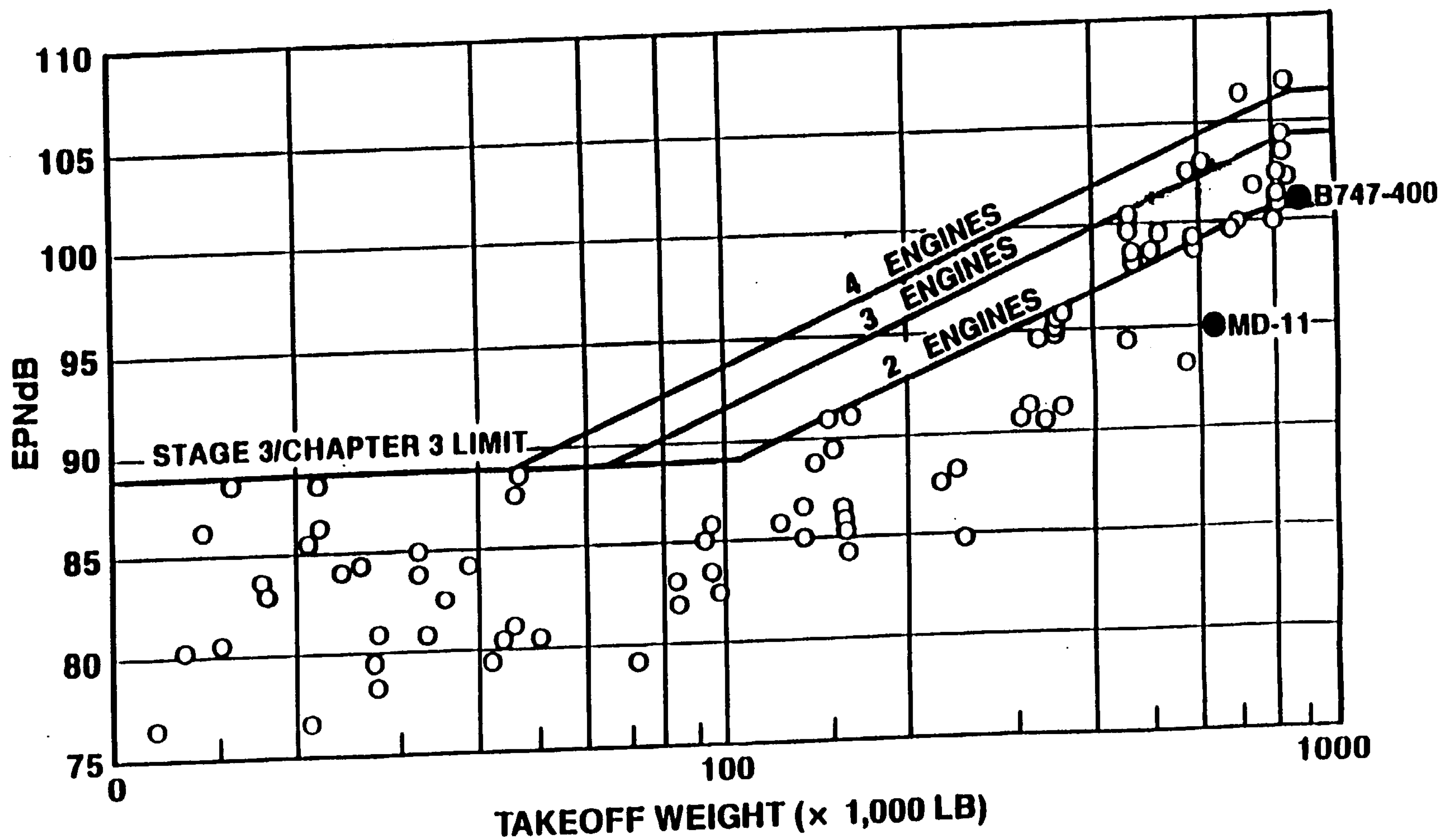


Figure 6. - FAR 36 Stage 3 Takeoff Noise Limits

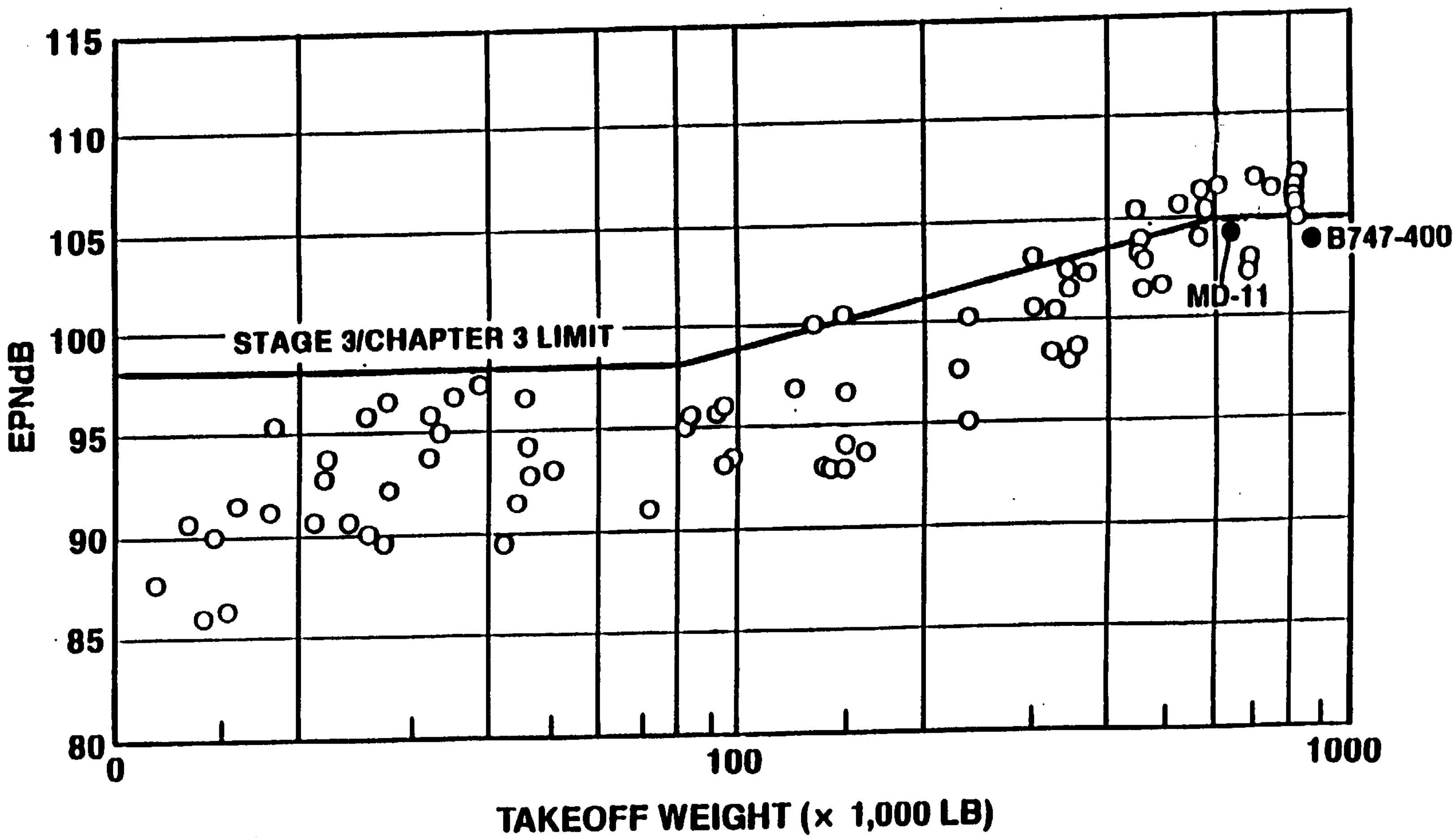


Figure 7. - FAR 36 Stage 3 Approach Noise Limits

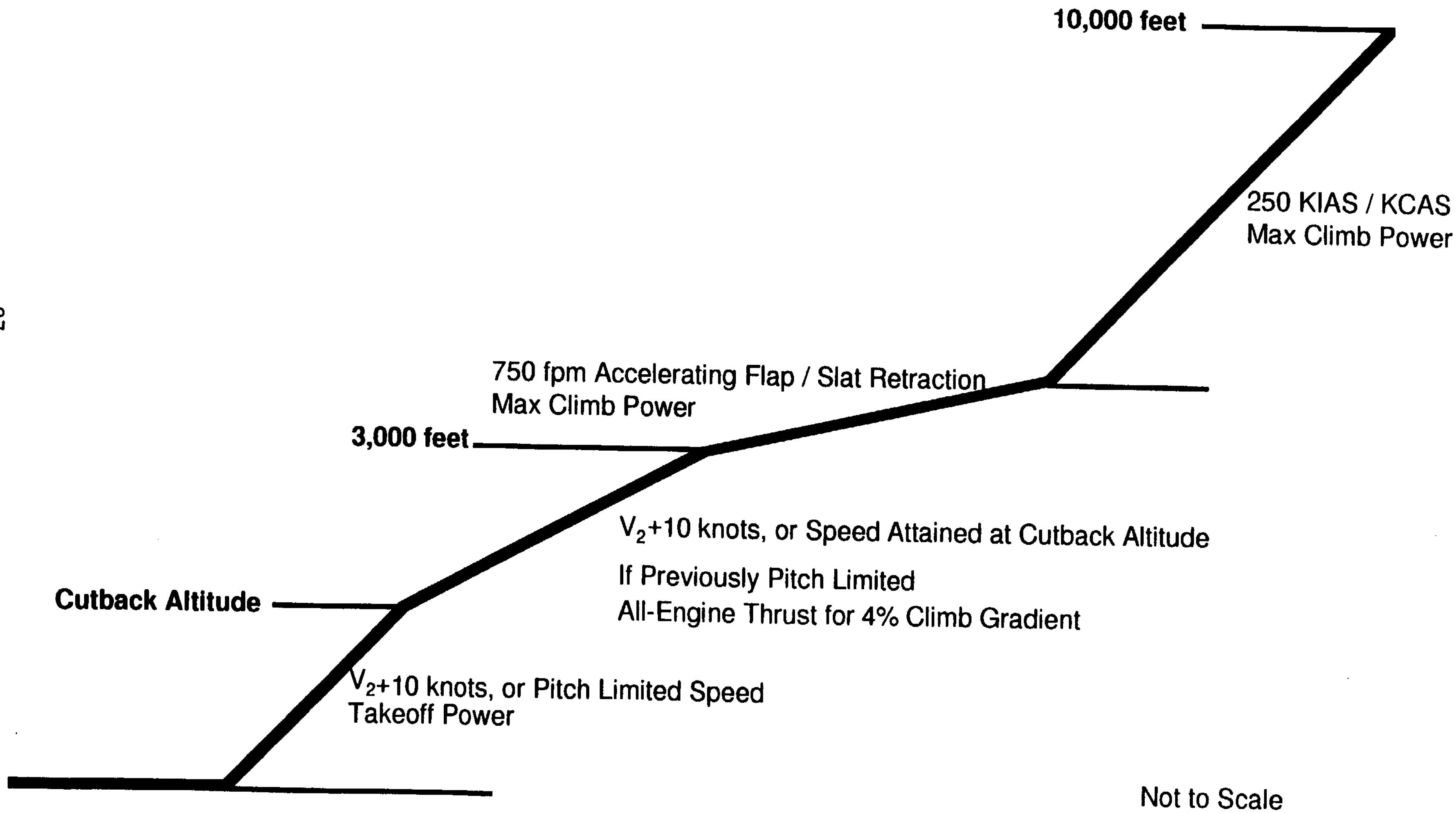


Figure 8. - Noise Certification Flight Procedure

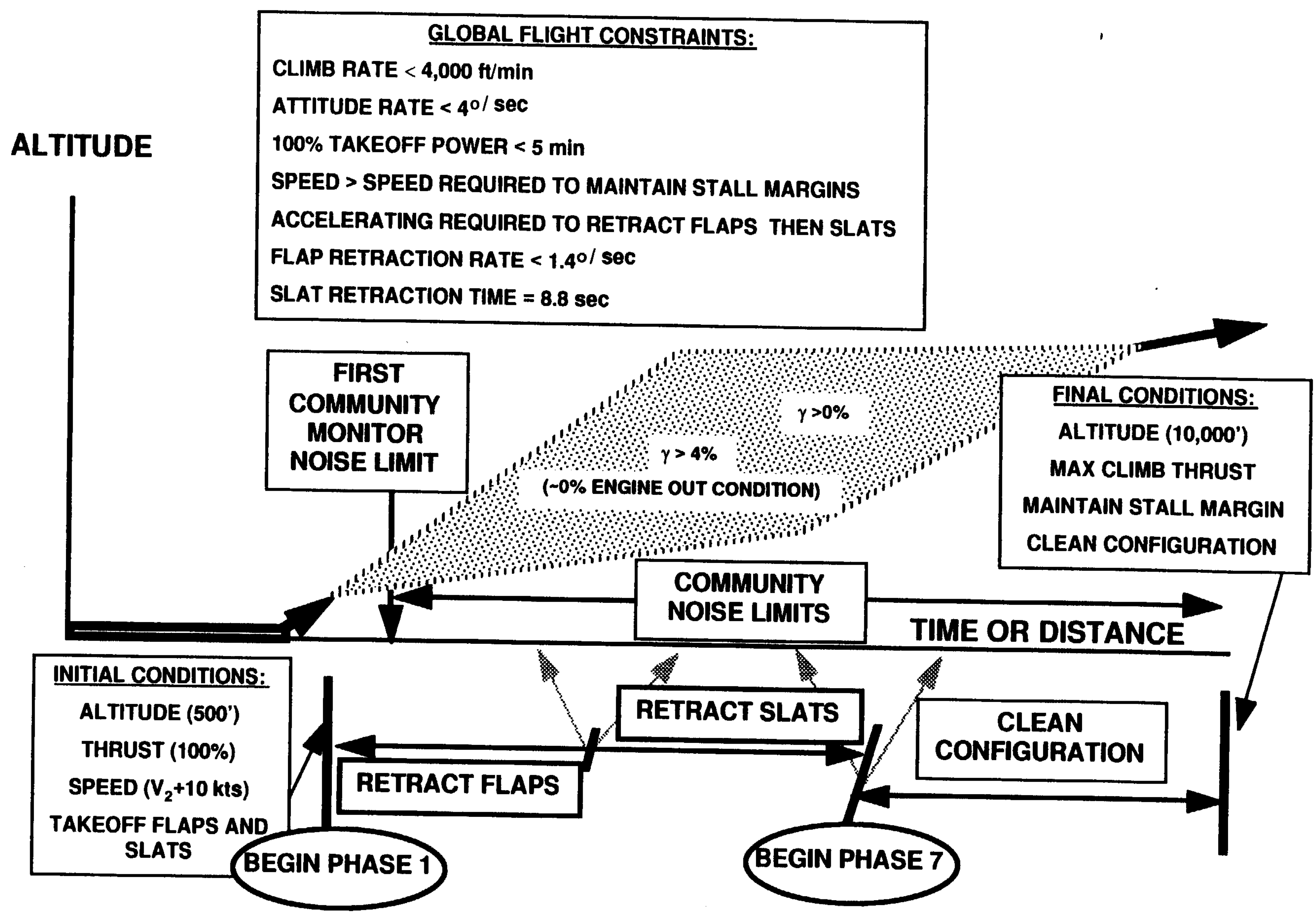


Figure 9. - OTIS Boundary Conditions for Flight Path Optimization

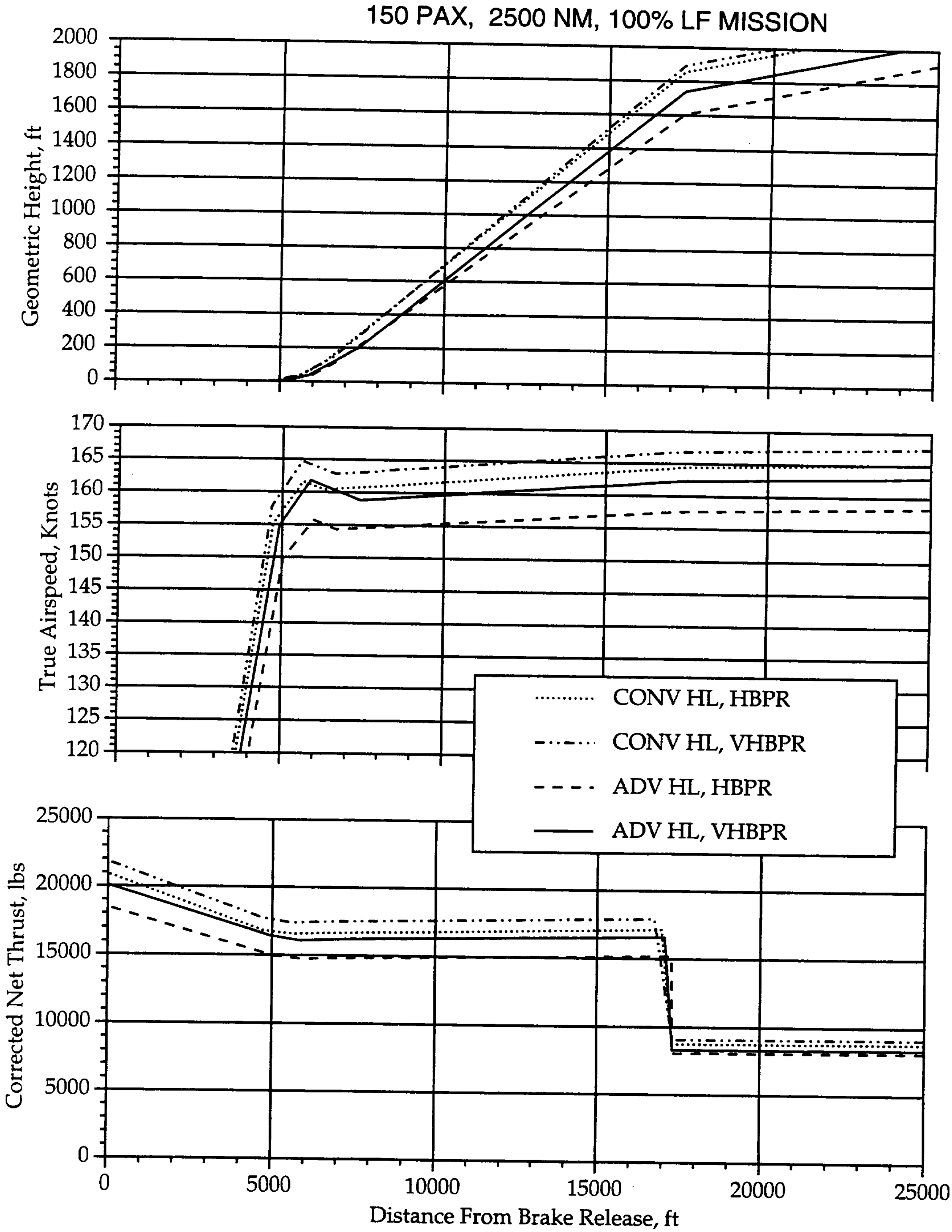


Figure 10. - Certification Flight Paths of Short-to-Medium Range Aircraft

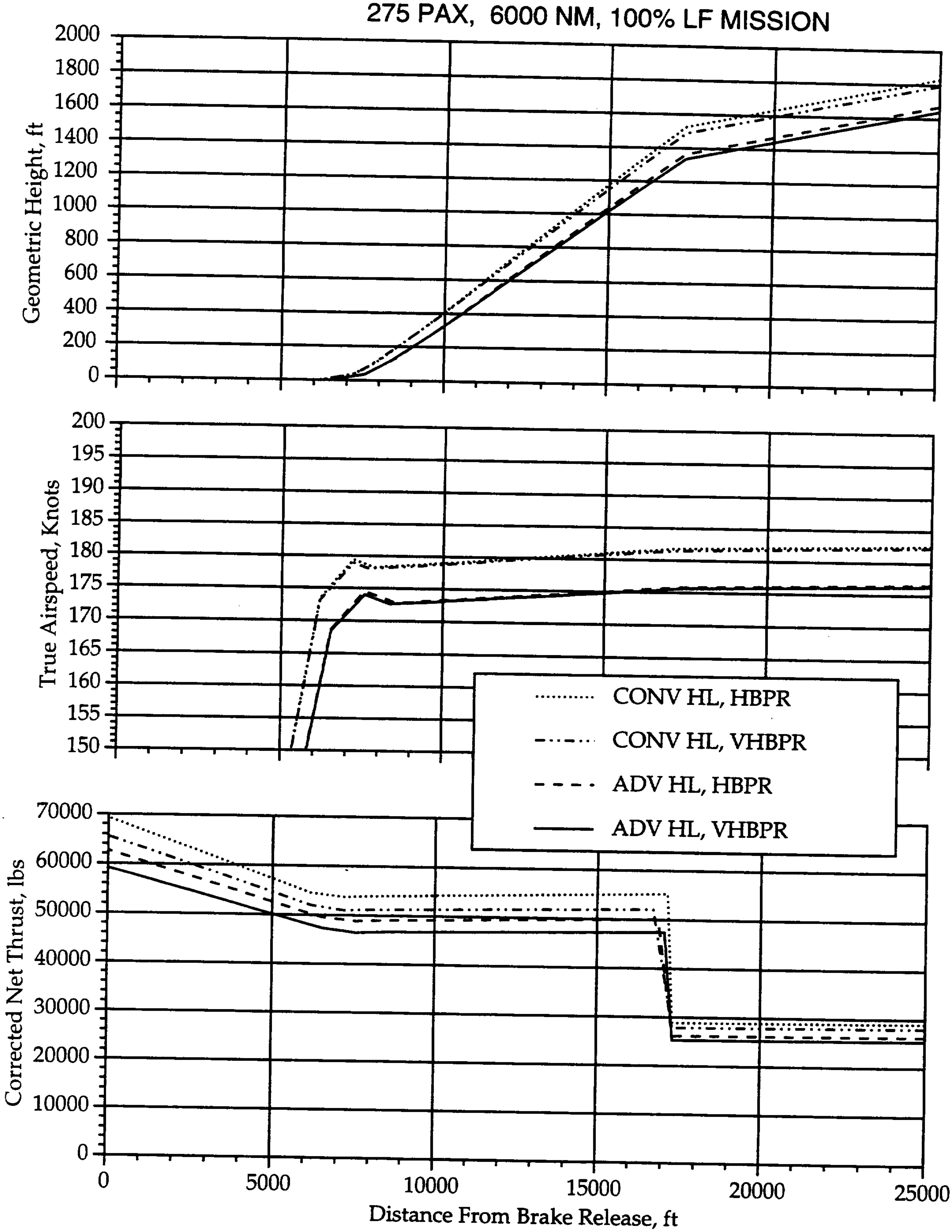


Figure 11. - Certification Flight Paths of Medium-to-Long Range Aircraft

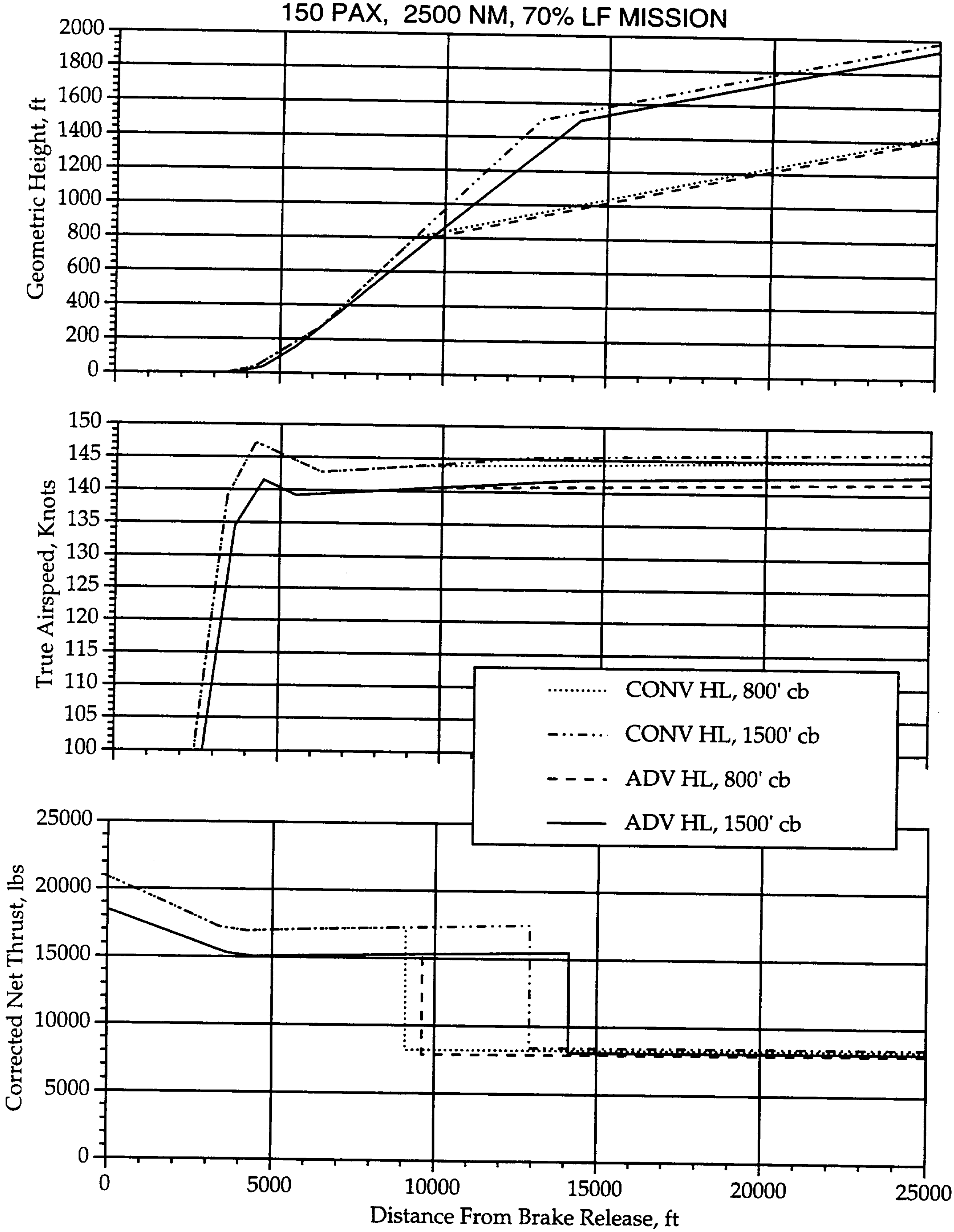


Figure 12. - Flight Paths of 70% Payload, 150 Passenger Aircraft for 2,500 NM Mission

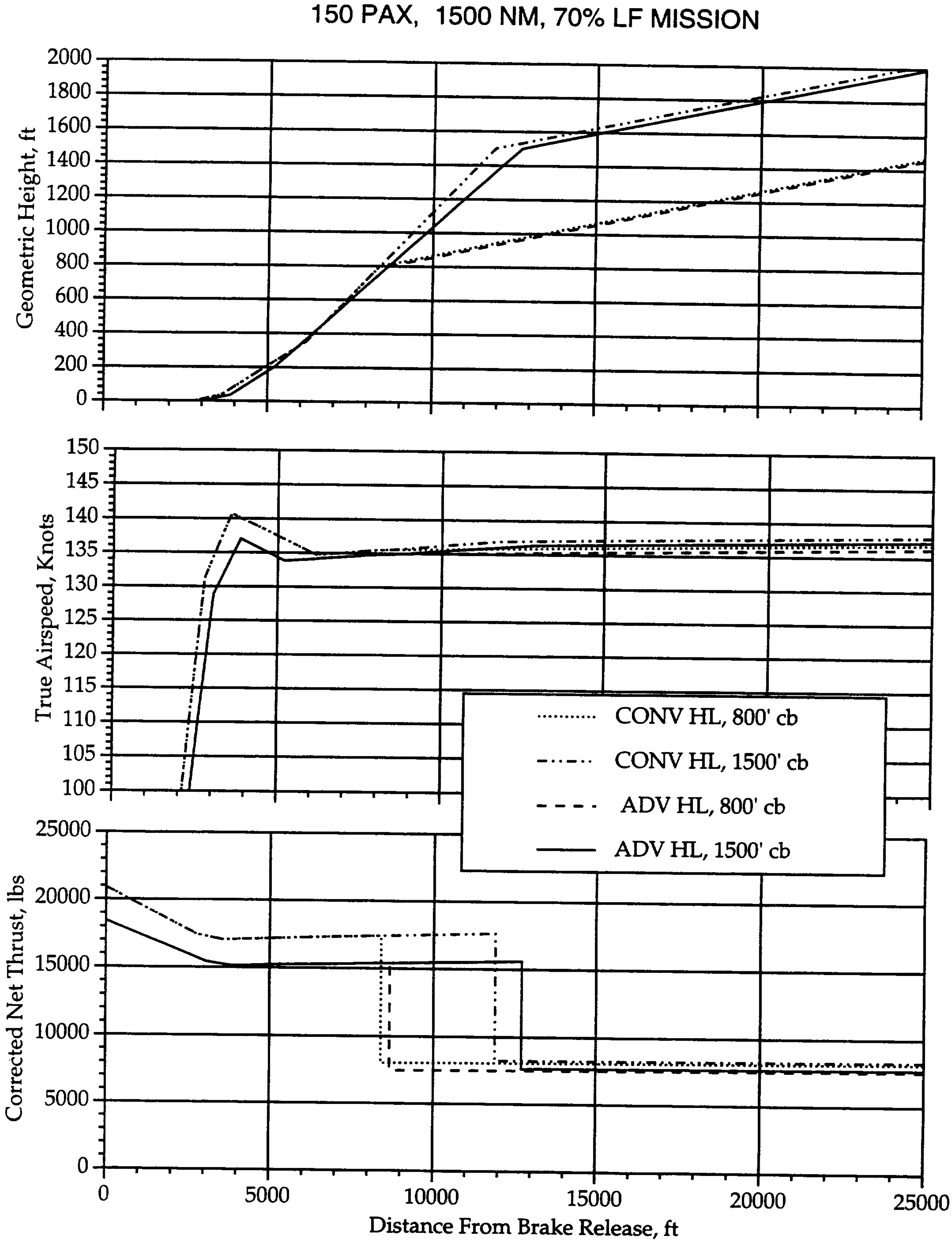


Figure 13. - - Flight Paths of 70% Payload, 150 Passenger Aircraft for 1,500 NM Mission

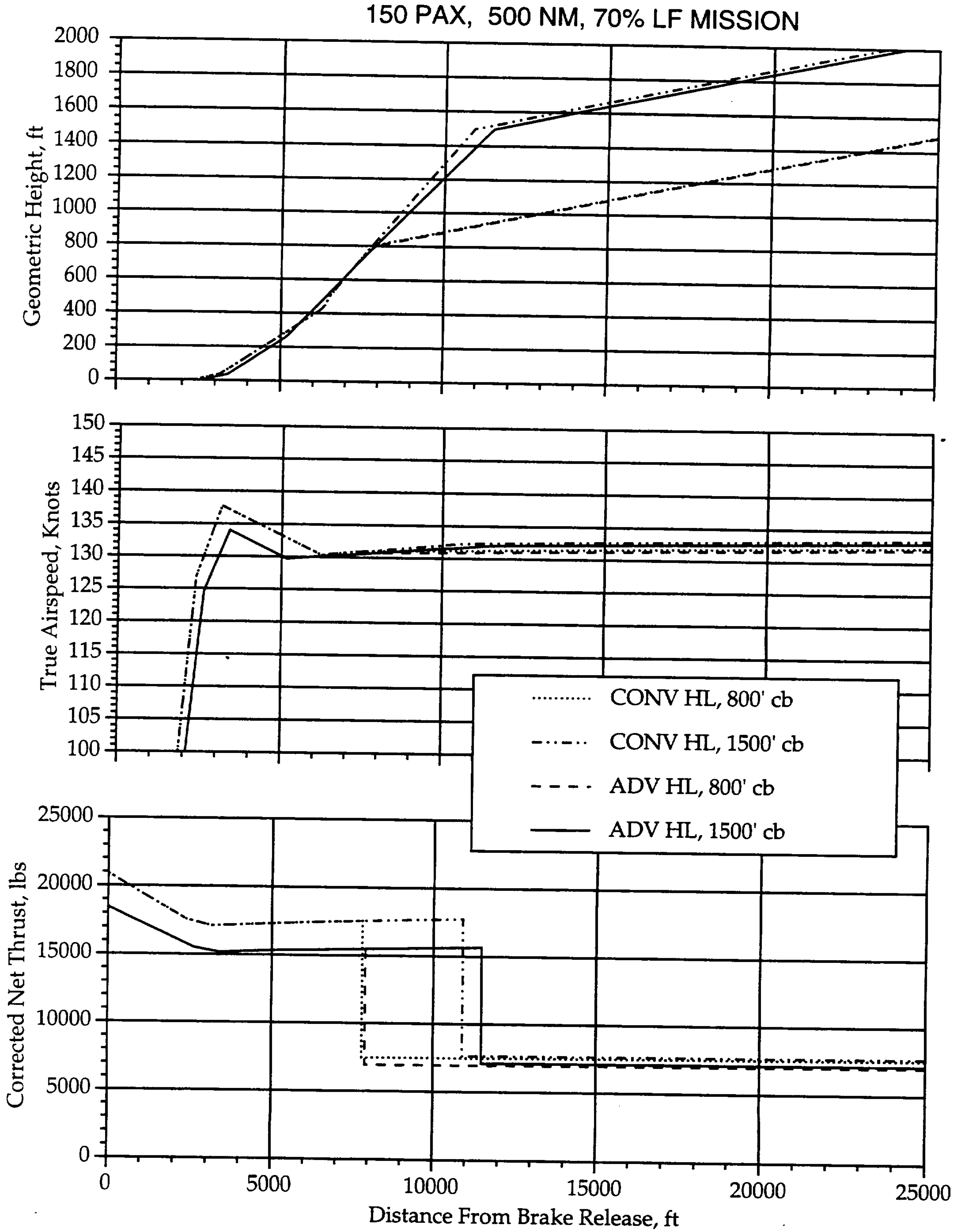


Figure 14. - Flight Paths of 70% Payload, 150 Passenger Aircraft for 500 NM Mission

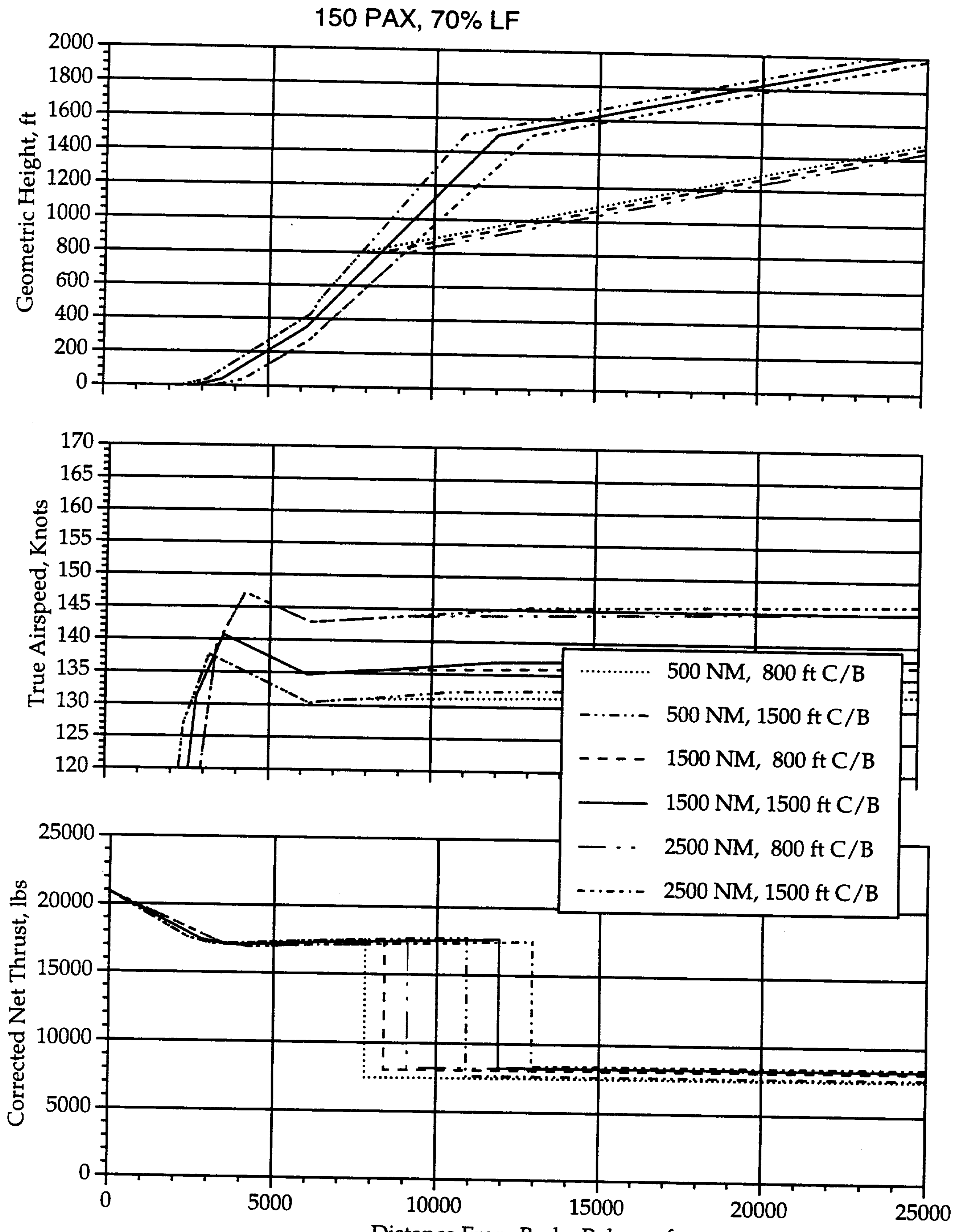


Figure 15. - Effect of Reduced Range Missions on Flight Paths for 150 Passenger Aircraft

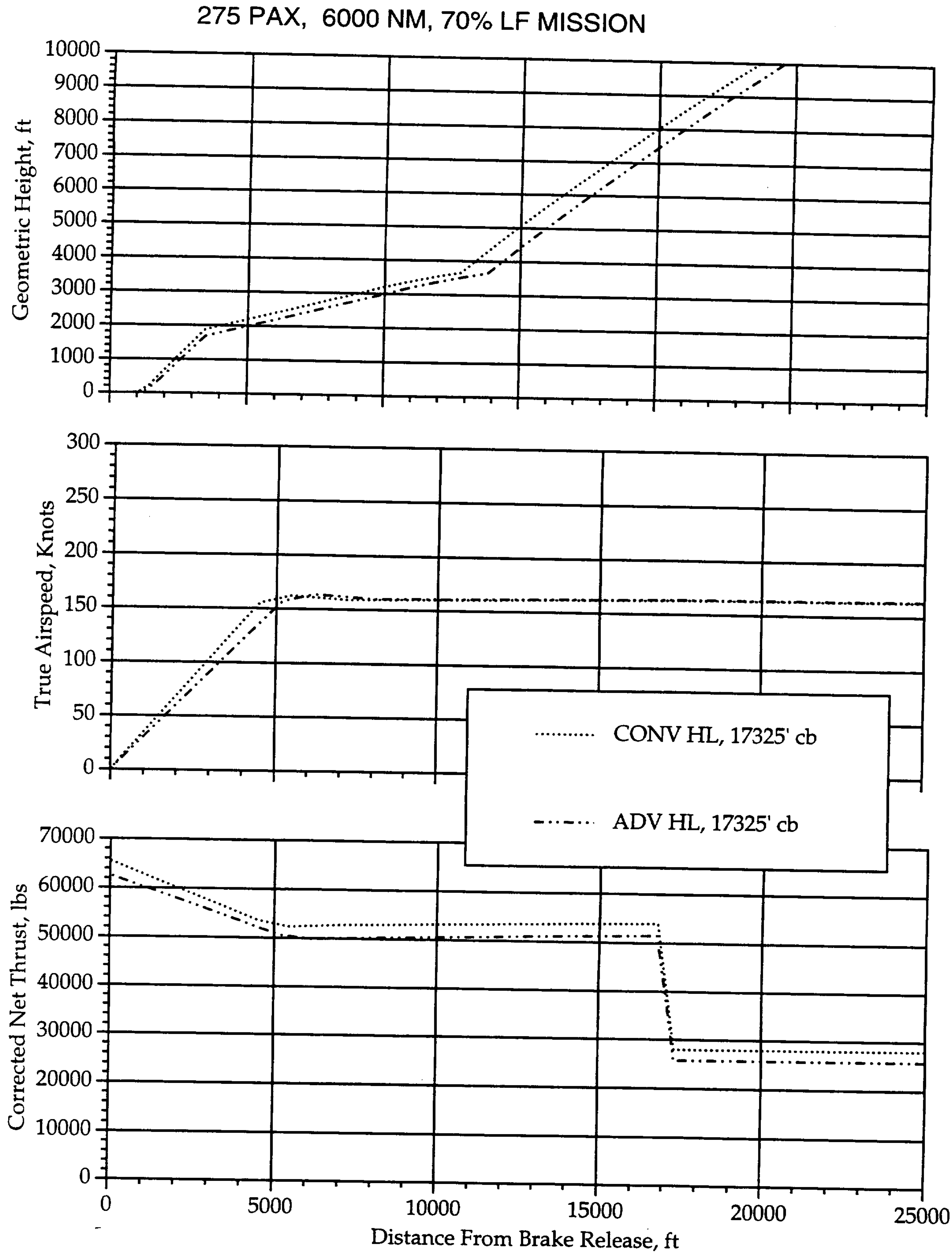


Figure 16. - Flight Paths of 70% Payload, 270 Passenger Aircraft for 6,000 NM Mission

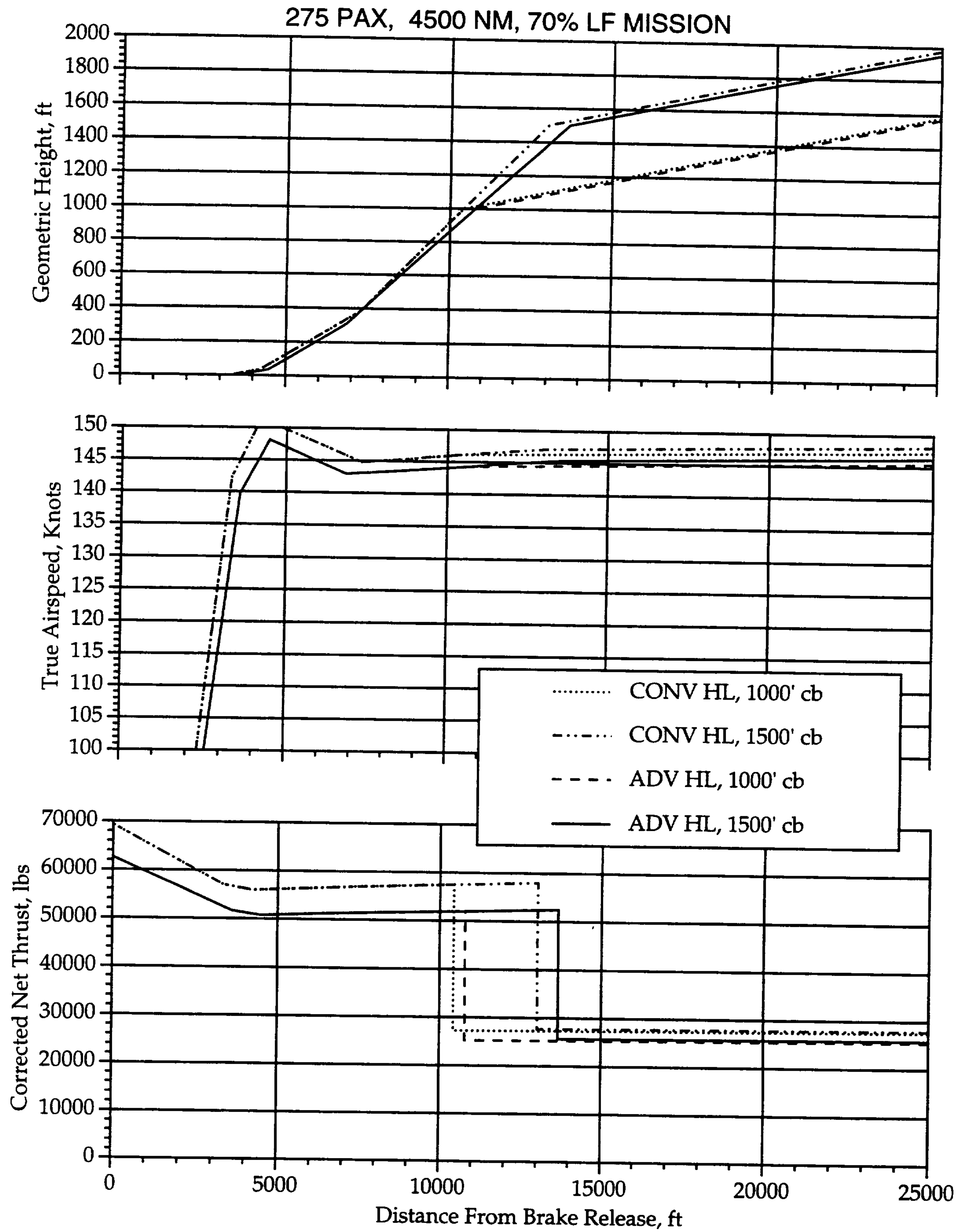


Figure 17. - Flight Paths of 70% Payload, 270 Passenger Aircraft for 4,500 NM Mission

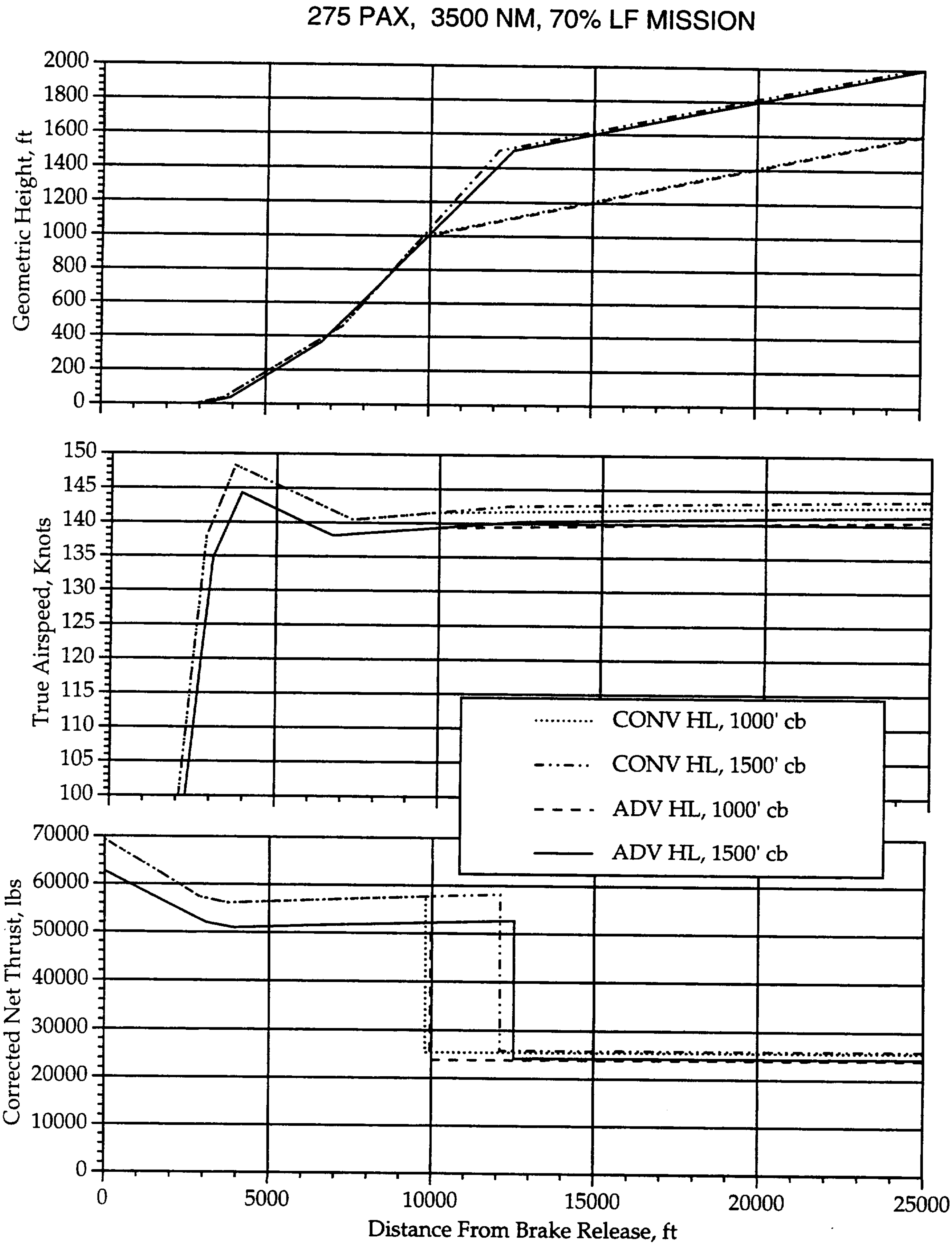


Figure 18. - Flight Paths of 70% Payload, 270 Passenger Aircraft for 3,500 NM Mission

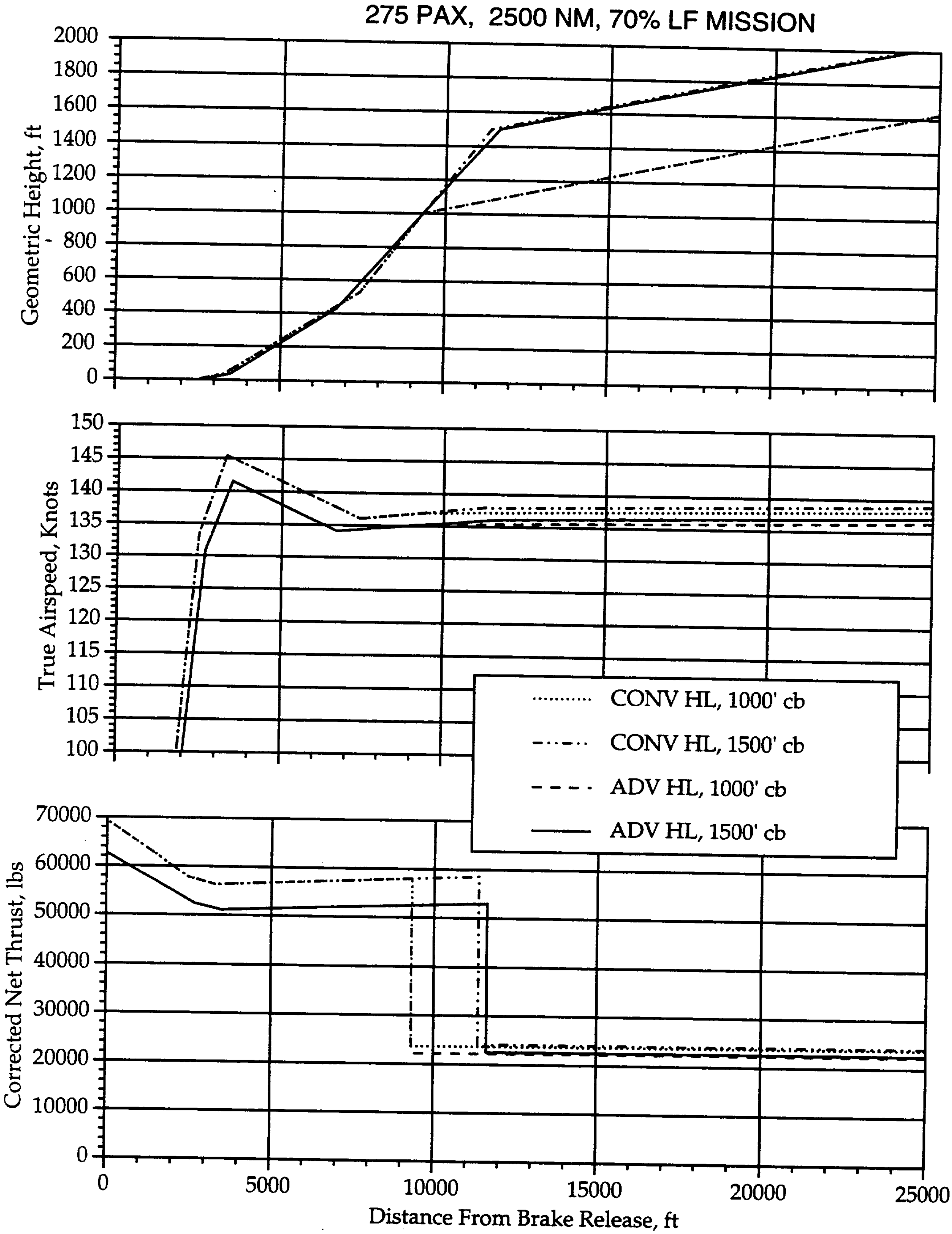


Figure 19. - Flight Paths of 70% Payload, 270 Passenger Aircraft for 2,500 NM Mission

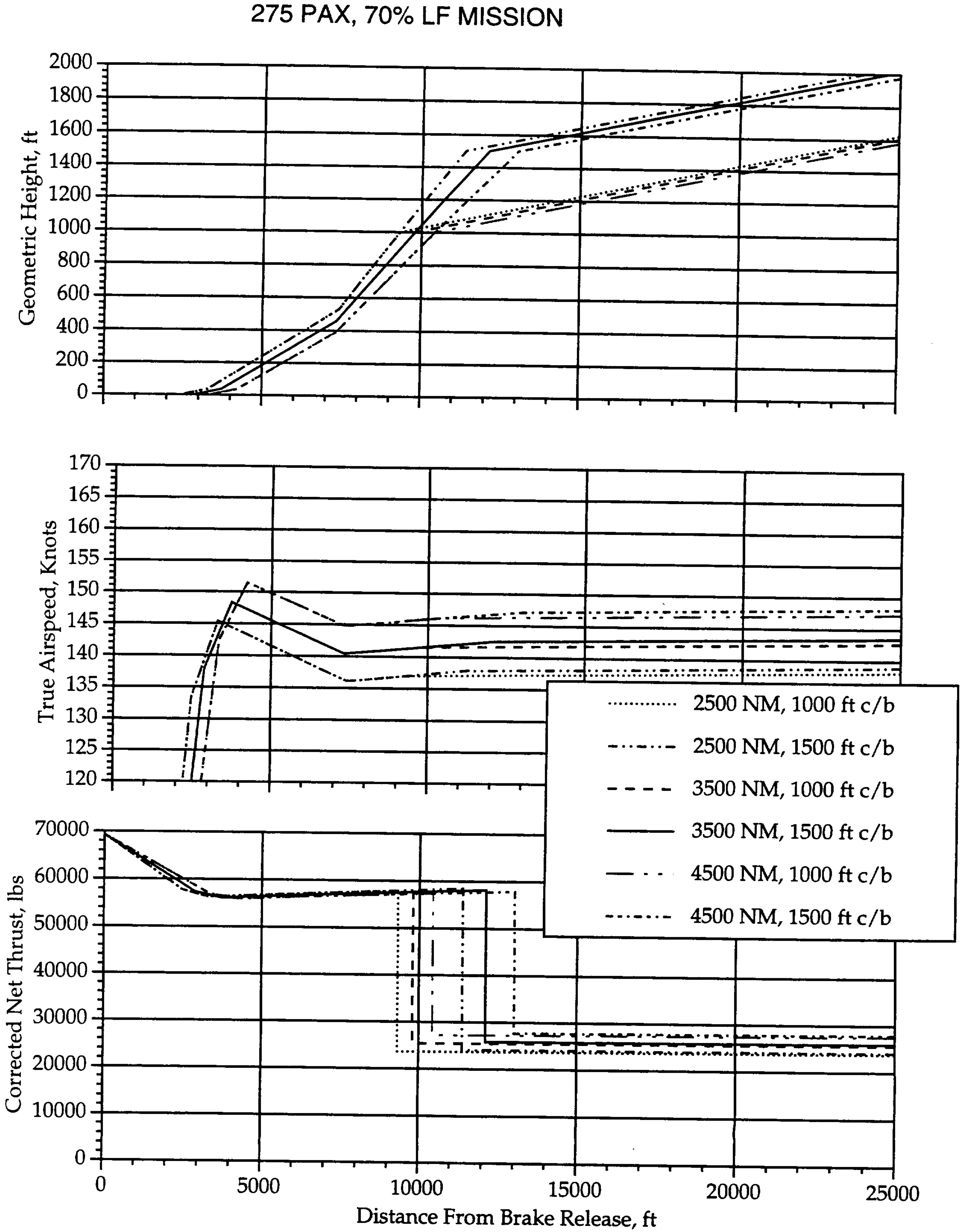
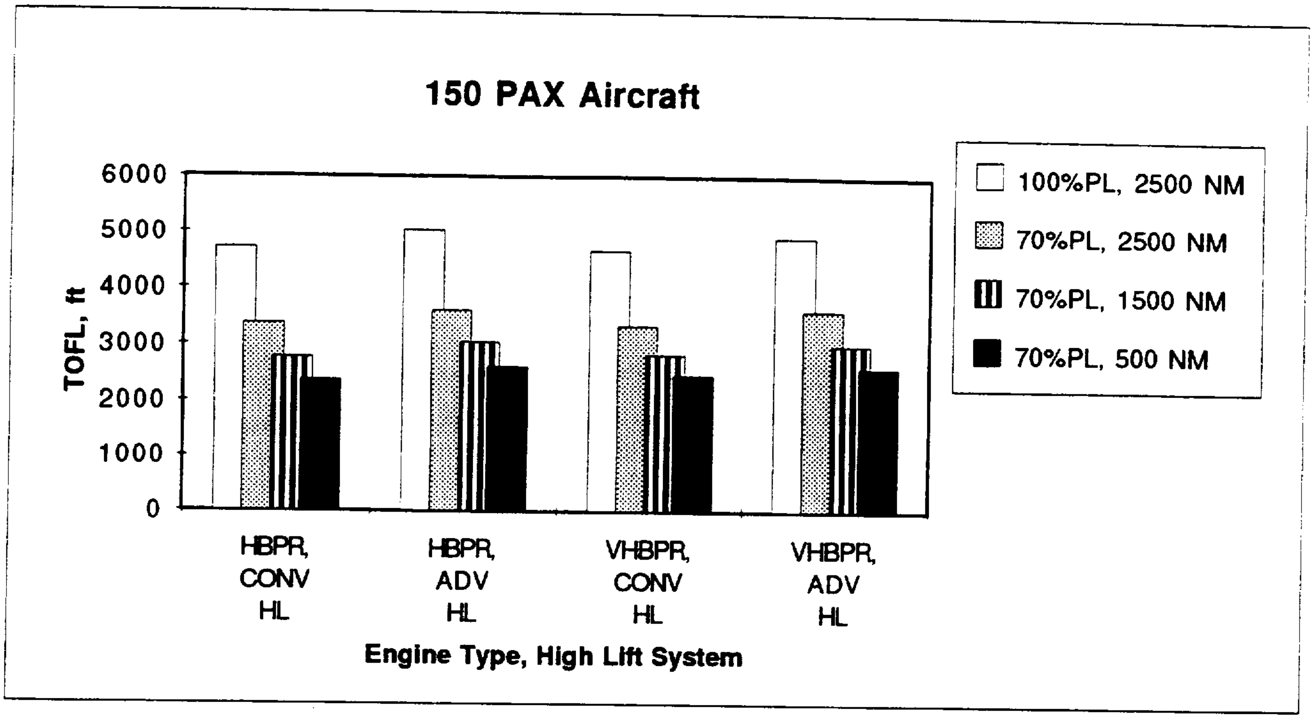


Figure 20. - Effect of Reduced Range Missions on Flight Paths for 275 Passenger Aircraft



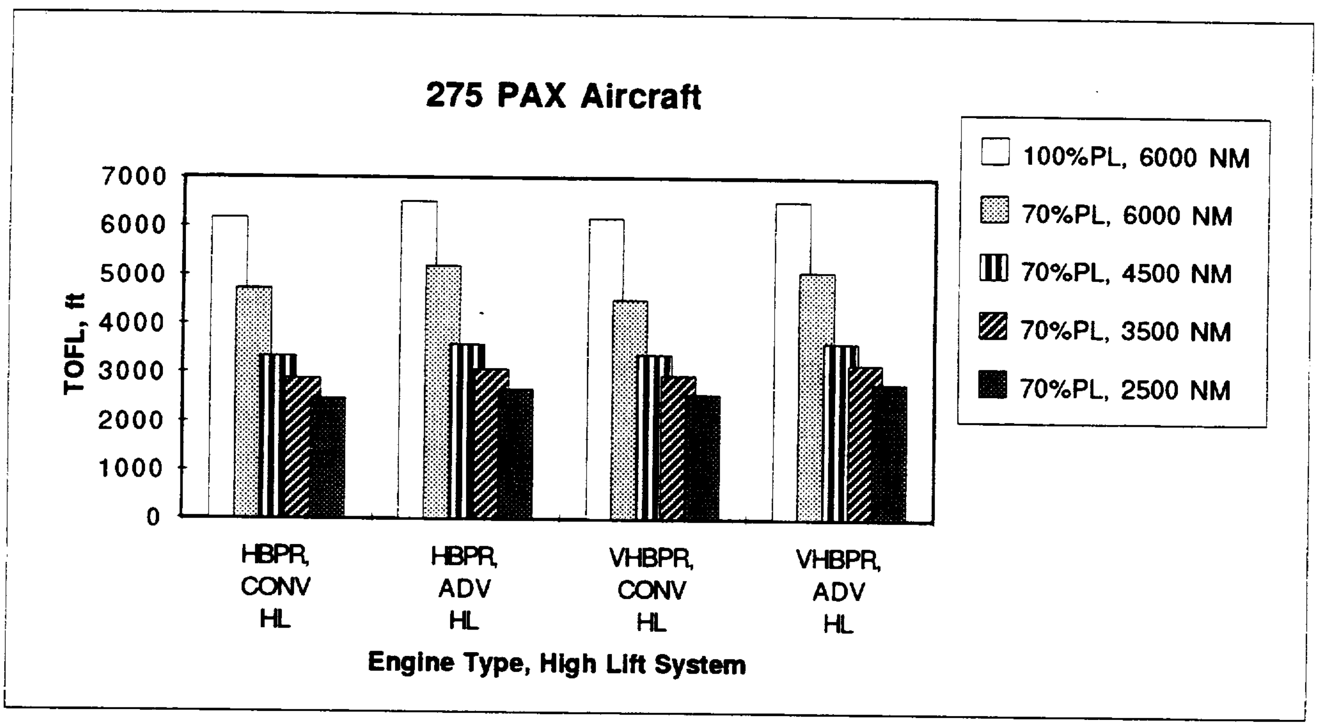


Figure 21. - Effects of Reduced Range on Takeoff Roll Distances

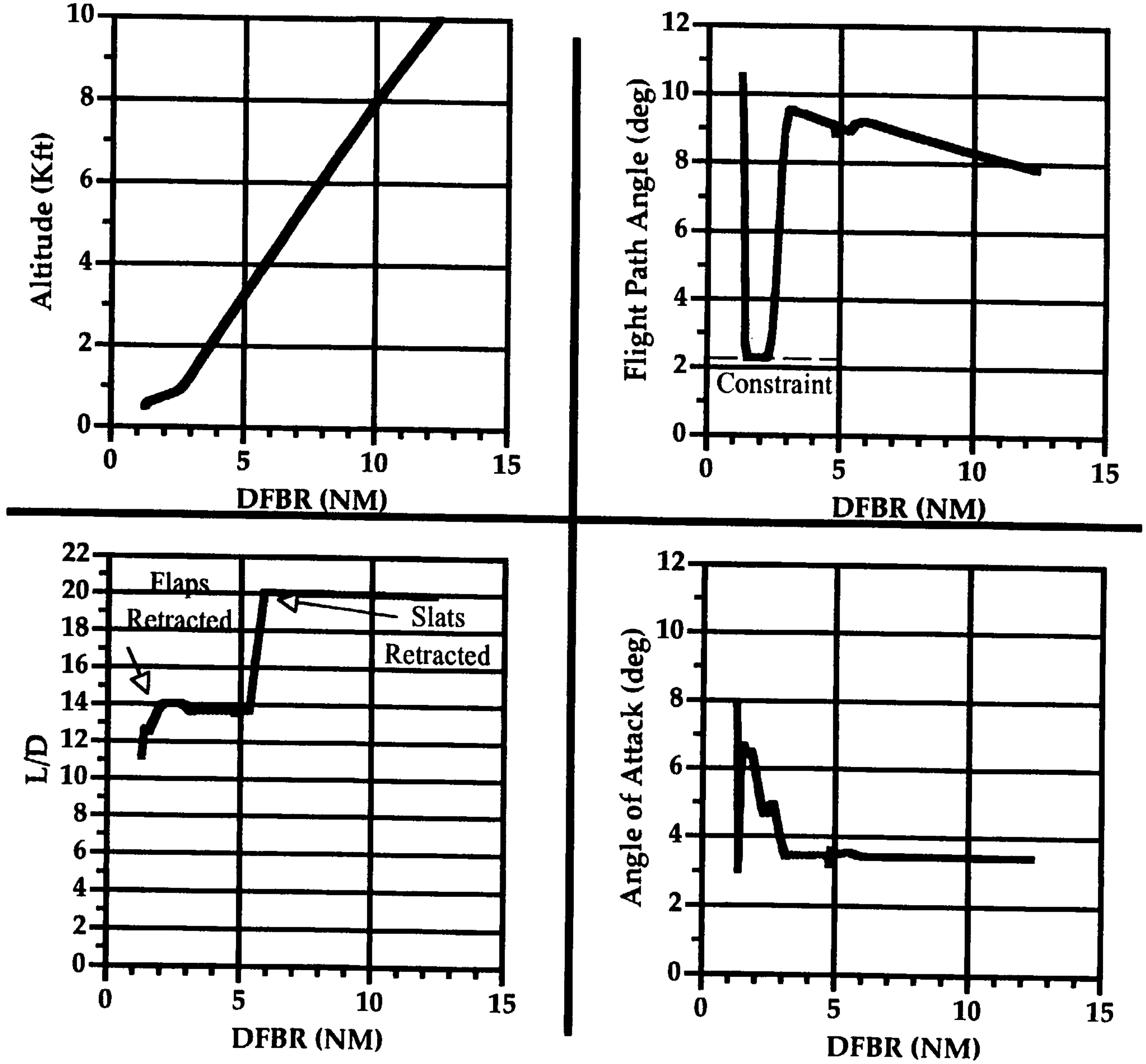


Figure 22. - OTIS Minimim Time Solution for a Conventional High Lift Configuration Without Noise Constraints

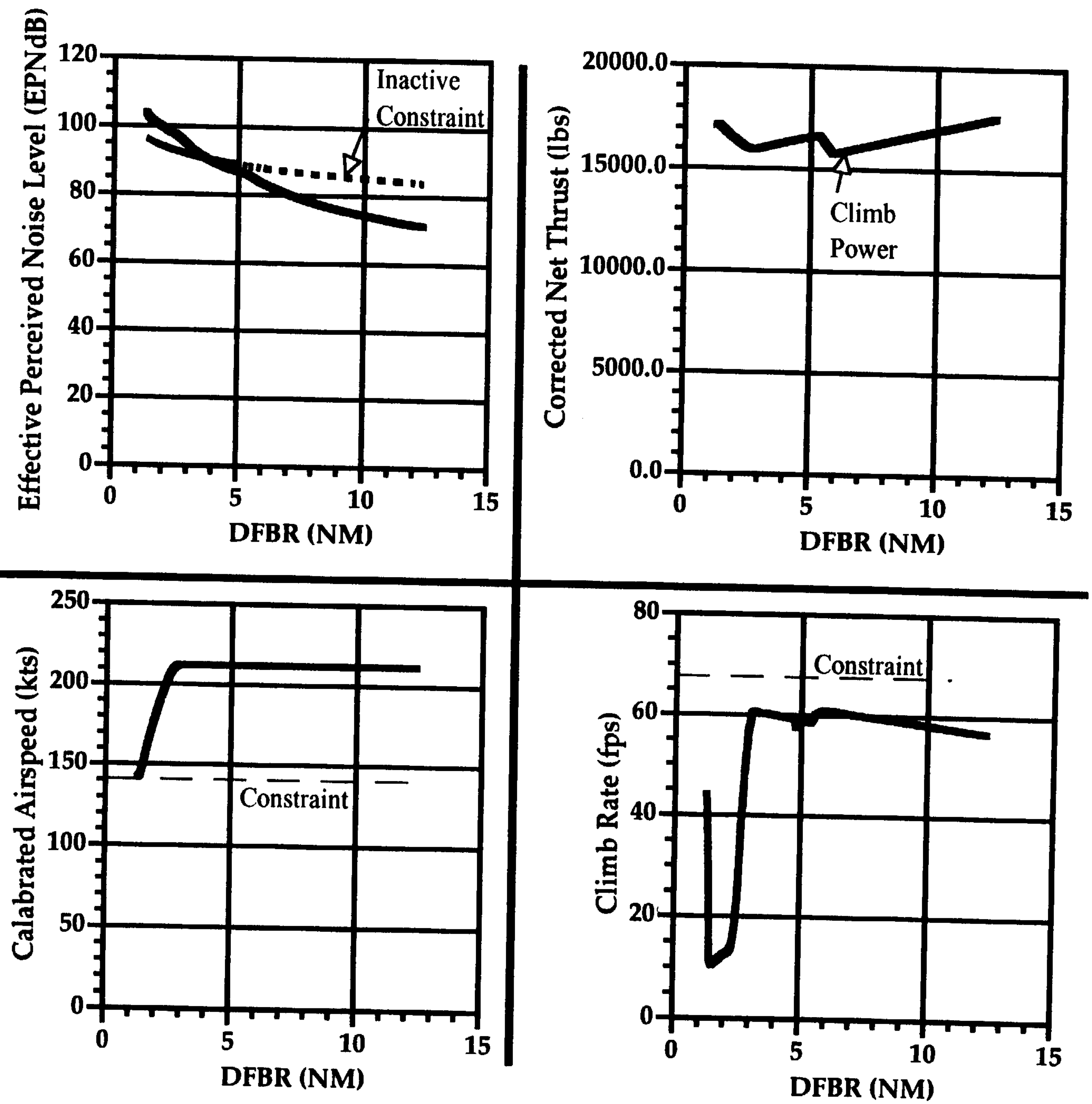


Figure 23. - OTIS Minimim Time Solution for a Conventional High Lift Configuration Without Noise Constraints (Continued)

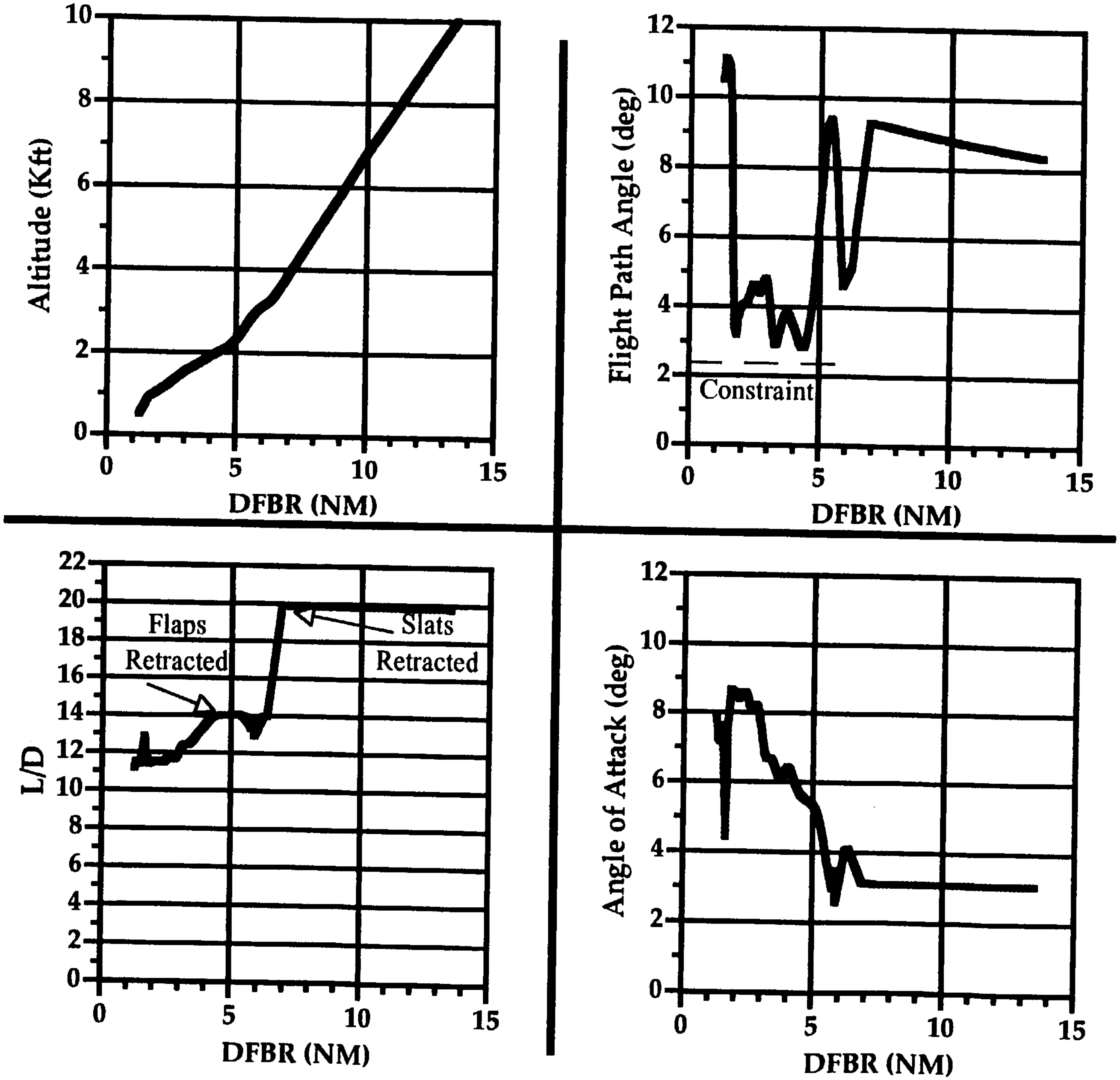


Figure 24. - OTIS Minimum Time Solution for a Conventional High Lift Configuration With Noise Constraints Imposed

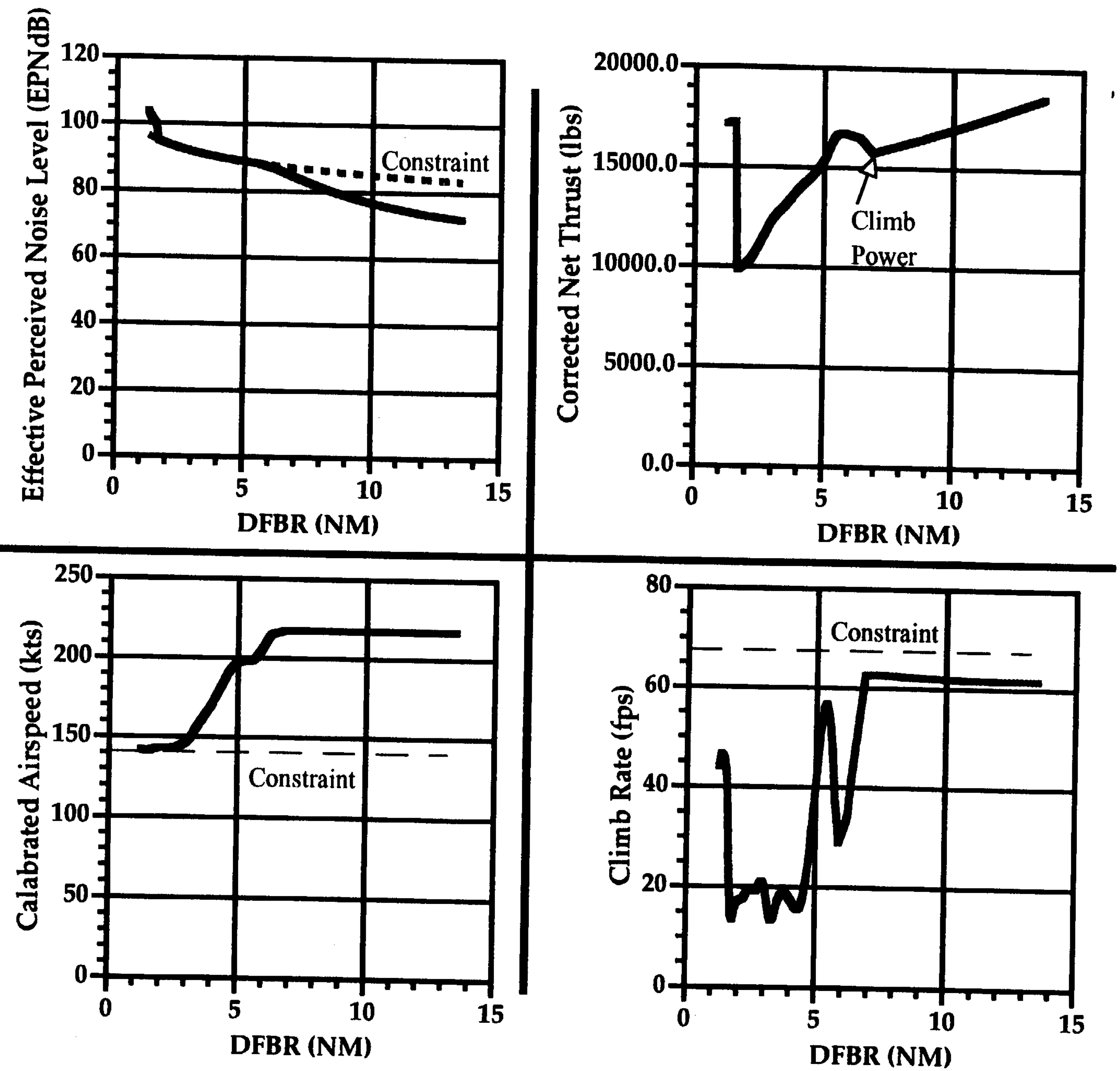


Figure 25. - OTIS Minimum Time Solution for a Conventional High Lift Configuration With Noise Constraints Imposed (Continued)

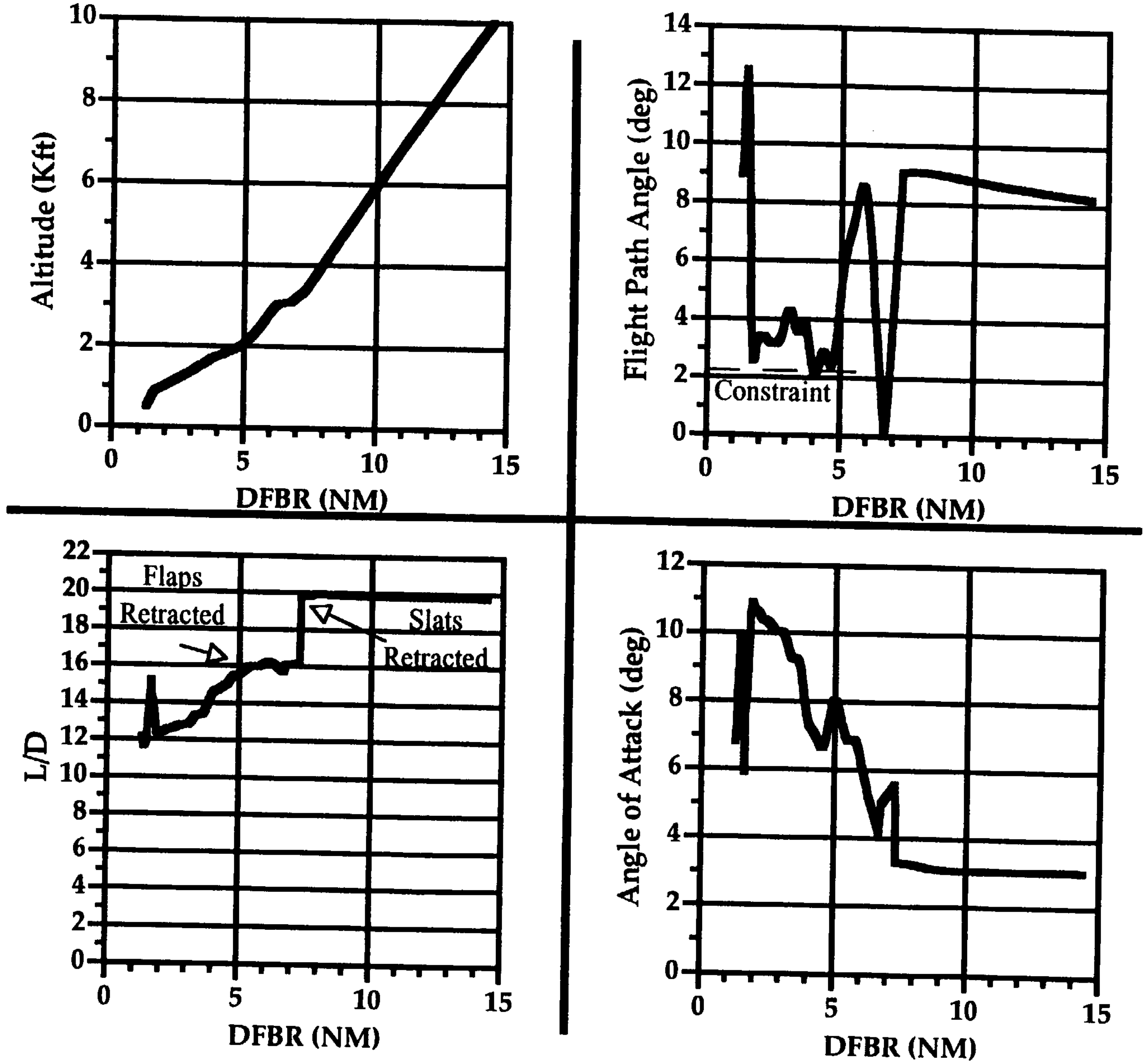


Figure 26. - OTIS Minimum Time Solution for an Advanced High Lift Configuration With Noise Constraints Imposed

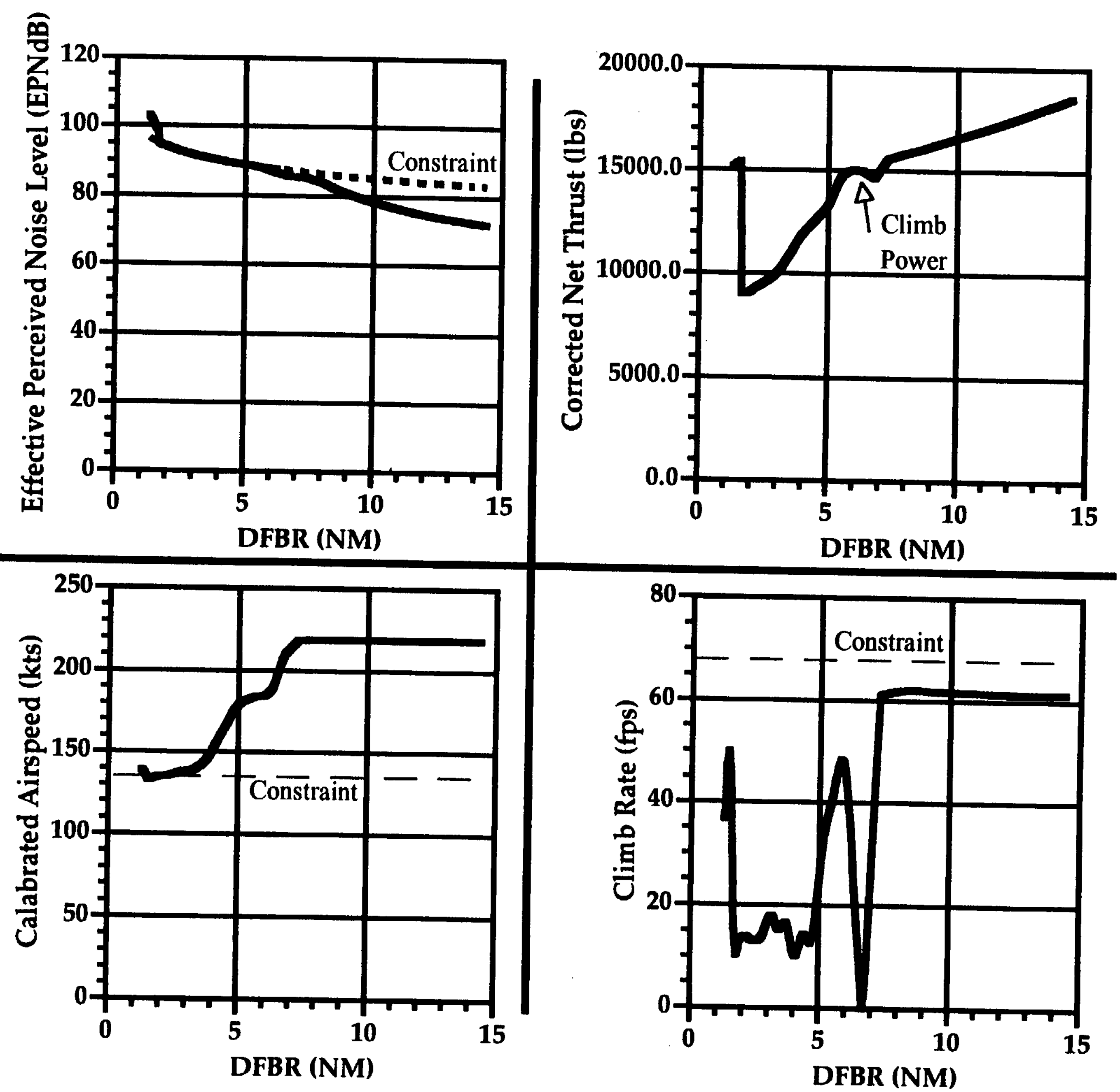


Figure 27. - OTIS Minimum Time Solution for an Advanced High Lift Configuration With Noise Constraints Imposed (Continued)

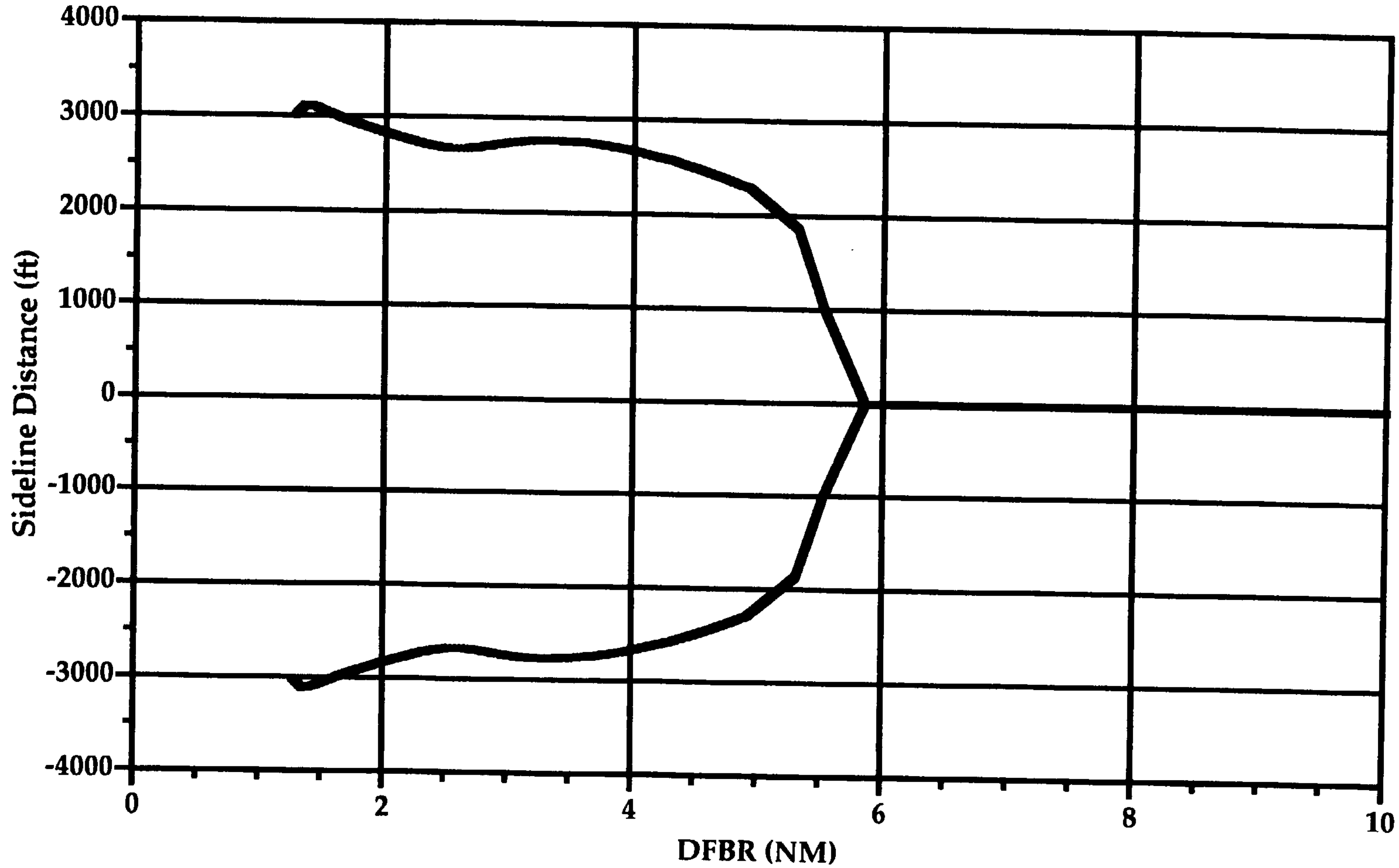


Figure 28. - 85 EPNL Contour for Conventional High Lift Configuration (No Noise Constraint)

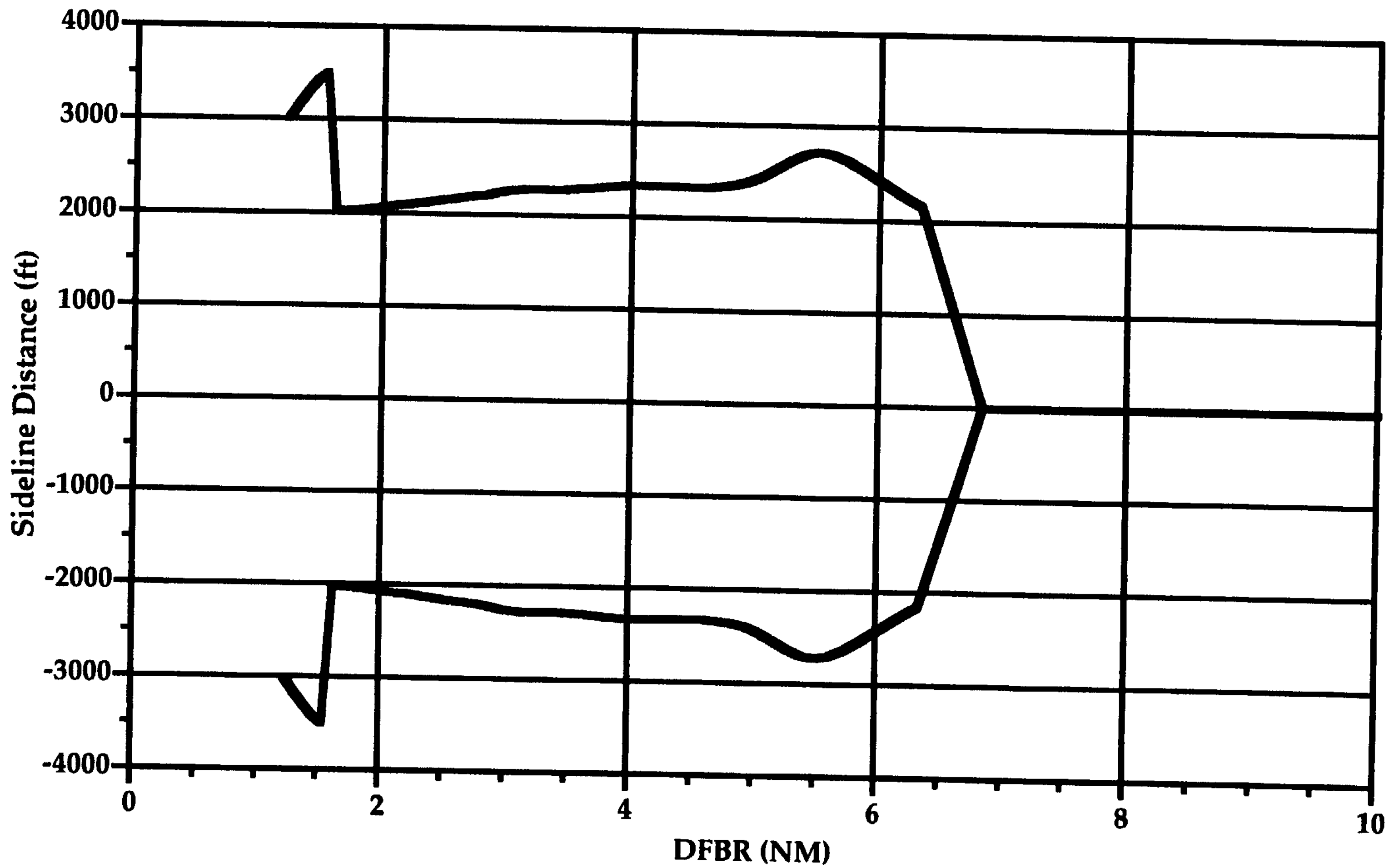


Figure 29. - 85 EPNL Contour for Conventional High Lift Configuration With Noise Constraints Imposed

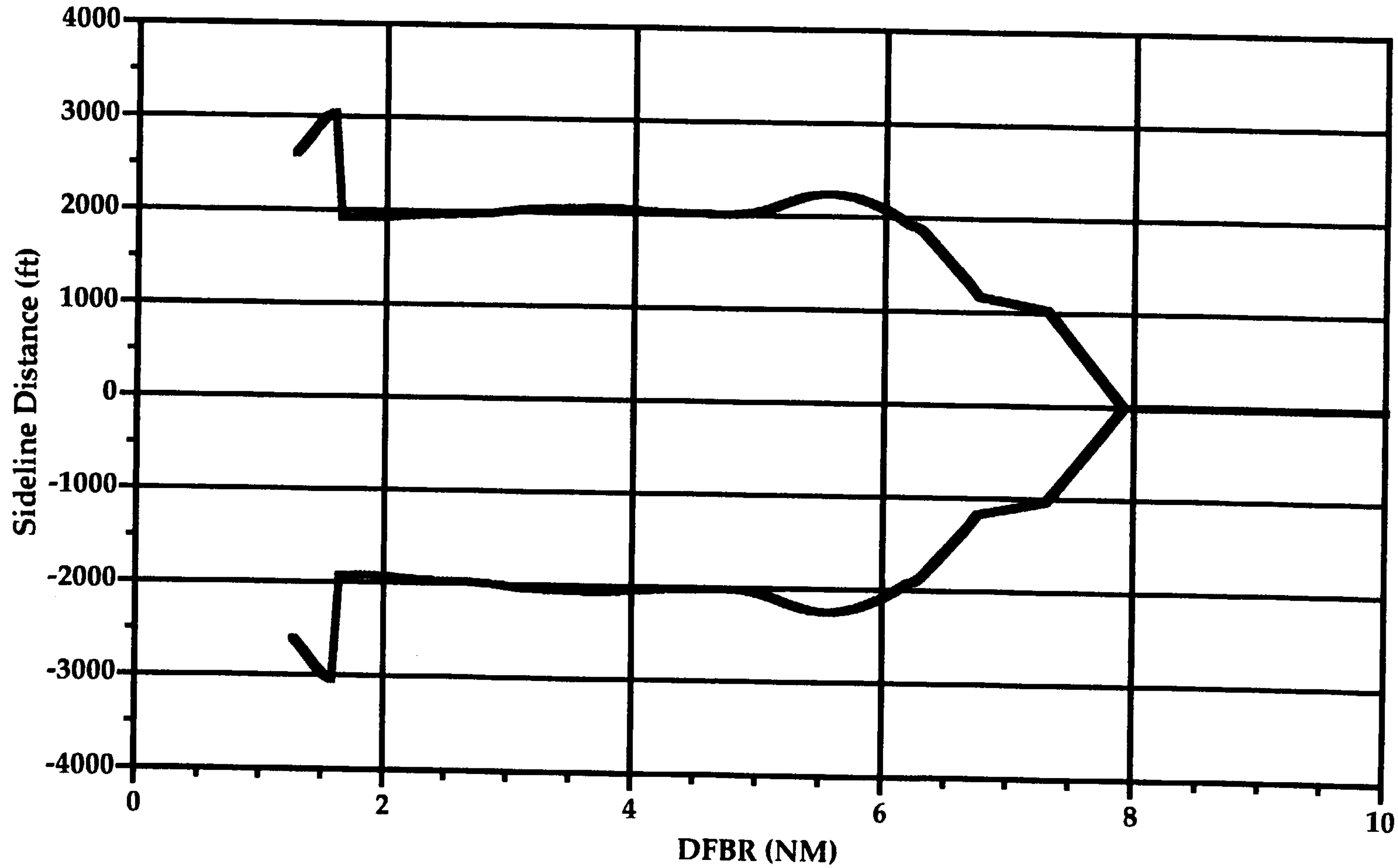


Figure 30. - 85 EPNL Contour for Advanced High Lift Configuration With Noise Constraints Imposed

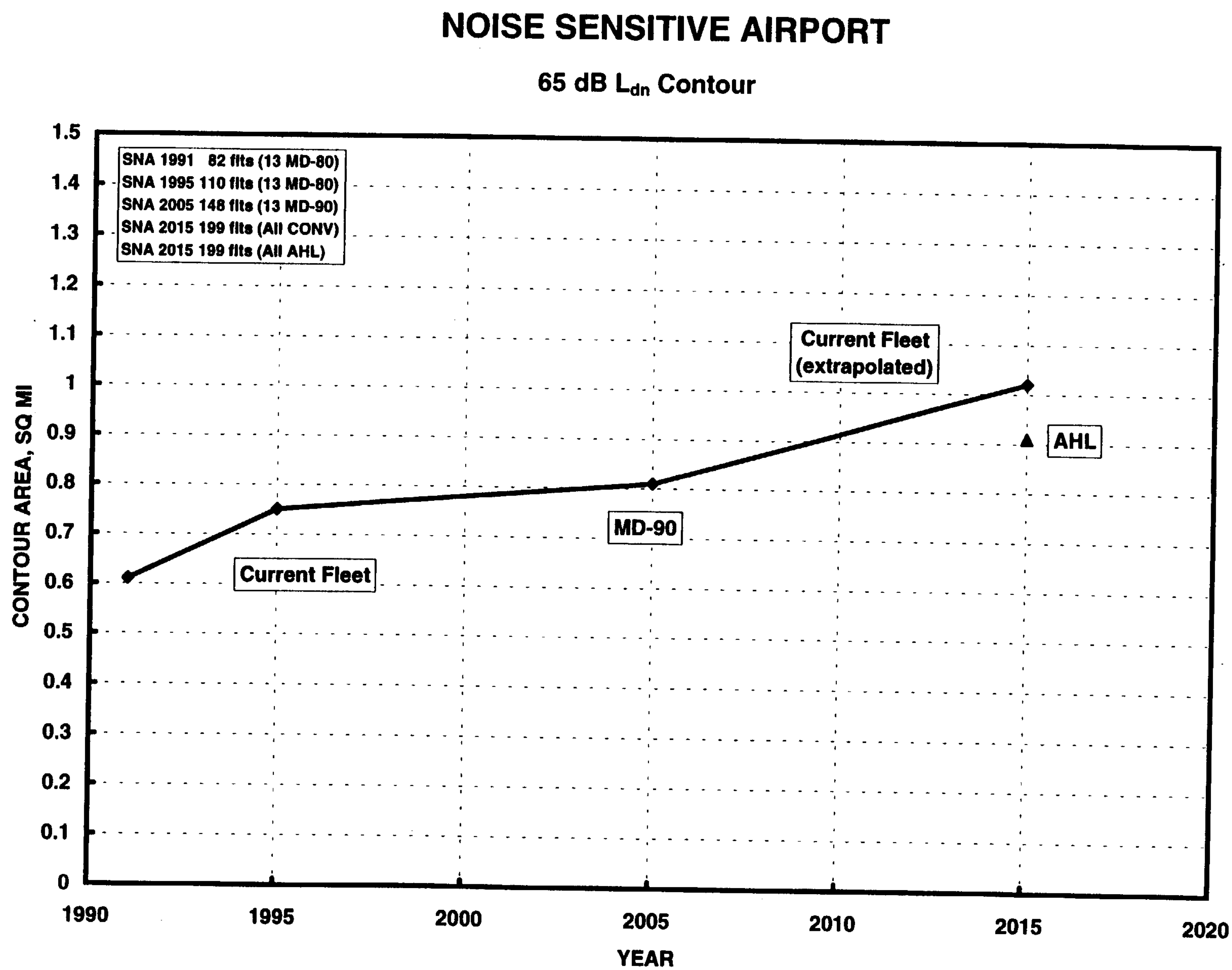


Figure 31. - 65 Ldn Noise Contours at a Small / Medium Noise Sensitive Airport

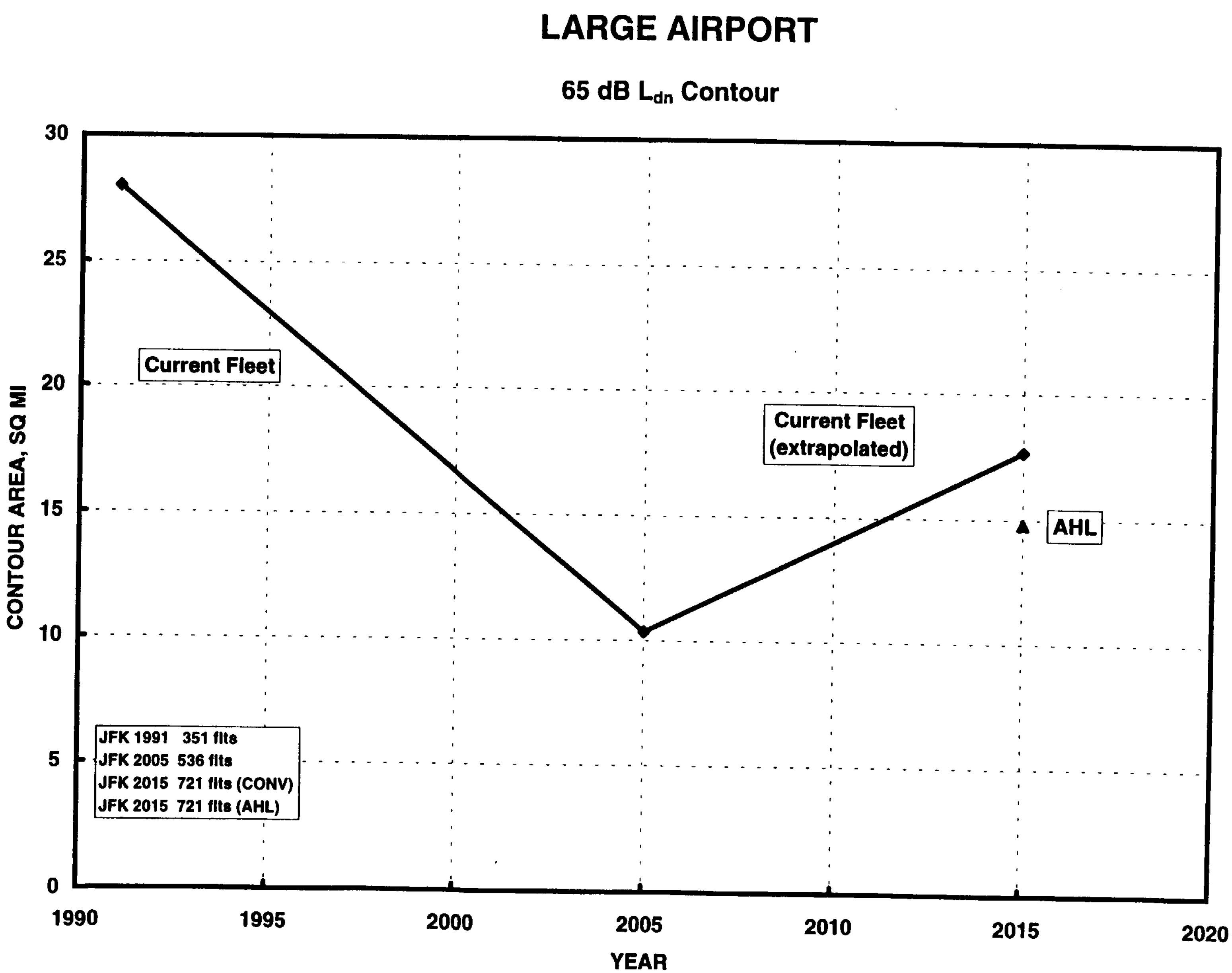


Figure 32. - 65 Ldn Noise Contours at a Large Capacity Airport

TABLE 1. - Performance Data for Short-to-Medium Range Aircraft

Engine / Bypass Ratio	MDA DTF023 / 6		MDA DTF022 / 16	
High Lift System	Conventional	Advanced	Conventional	Advanced
Sizing	Performance	Noise	Performance	Noise
Sw (Sq Ft)	1,075	**1,075**	1,045	**1,045**
Fn (Lb)	20,900	18,450	21,800	20,075
MTOW (Lb)	135,500	136,700	138,200	139,200
OEW (Lb)	75,800	76,900	80,500	81,600
Block Fuel (Lb)	23,900	24,100	22,300	22,300
Block Time (Hr)	6.05	6.06	6.03	6.03
Wt/Sw (Lb/Sq Ft)	126.0	127.2	132.2	133.2
Fn/Wt	0.309	0.270	0.316	0.288
ICA (Ft)	38K+(Buffet)	37K+(Cl Cell)	37K+(Buffet)	35K+(Cl Cell)
Vappr (KEAS)	125.2	129.1	129.4	128.1
Fn appr - 2 engines (Lb)	7,730	4,015	8,130	6,107
Appr Weight (Lb)	112,000	113,000	116,300	117,300
TOFL (Ft)	**7,000**	**7,000**	**7,000**	**7,000**
1st Seg Grad (%)	1.40	1.49	1.40	1.45
2nd Seg Grad (%)	2.40	2.40	2.40	2.40
V2 (KEAS)	146.7	140.8	149.0	145.0
L/D				
Start Cruise @ 35000	17.90	17.99	17.39	17.54
End Cruise @ 39000	17.75	17.83	17.22	16.77*
SFC				
Start Cruise @ 35000	0.579	0.577	0.510	0.509
End Cruise @ 39000	0.577	0.575	0.505	0.511*

* at 39,000 Ft

Mission Rules: 150 Seats, 31,500 Lb Payload, 2,500 NM Range, 0.78 Cruise Mach No.

TABLE 2. - Performance Data for Medium-to-Long Range Aircraft

Engine / Bypass Ratio	MDA DTF023 / 6		MDA DTF022 / 16	
High Lift System	Conventional	Advanced	Conventional	Advanced
Sizing	Performance	Noise	Performance	Noise
Sw (Sq Ft)	3,240	**3,240**	3,125	**3,125**
Fn (Lb per Engine)	69,350	62,650	65,600	59,200
MTOW (Lb)	449,500	453,900	432,900	437,000
OEW (Lb)	224,900	230,100	230,200	234,300
Block Fuel (Lb)	148,700	148,200	131,600	131,500
Block Time (Hr)	13.10	13.11	13.07	13.07
Wt/Sw (Lb/Sq Ft)	138.8	140.1	138.5	139.9
Fn/Wt	0.309	0.276	0.303	0.271
ICA (Ft)	39.7K+ (CL)	38.6K+(CL)	37.8K+(CL)	36.2K+(CL)
Vappr (KEAS)	119.2	124.8	121.5	127.1
Fn appr (Lb per Shipset)	22,150	13,490	22,100	13,800
Appr Weight (Lb)	301,900	306,700	302,300	306,500
TOFL (Ft)	**9,000**	**9,000**	**9,000**	**9,000**
1st Seg Grad (%)	0.67	0.83	0.62	0.78
2nd Seg Grad (%)	2.40	2.40	2.40	2.40
V2 (KEAS)	164.2	158.8	164.0	158.3
L/D				
Start Cruise @ 35000	20.11	20.17	19.48	19.58
End Cruise @ 43000	19.63	19.68	19.00	18.72*
SFC				
Start Cruise @ 35000	0.607	0.601	0.537	0.531
End Cruise @ 43000	0.617	0.610	0.539	0.533*

* at 39,000 Ft

Mission Rules: 275 Seats, 57,750 Lb Payload, 6,000 NM Range, 0.83 Cruise Mach No.

Table 3. - OTIS PHASE DESCRIPTION

Problem: Minimum time of flight to 10,000 feet altitude. With and without noise constraints.

Phase 1: Initial conditions set at 500 feet altitude. End phase when closest approach = 10,000' DFBR.

Phase 2: End phase at 3000 feet altitude.

Phase 3: 1 to 10 second period to retract flaps if still extended. End phase $\delta_f=0$.

Phase 4: Fly with $\delta_f=0$ and slats extended for 1 second if slats are still extended.

Phase 5: 7.8 seconds to retract slats if still extended (wing is clean).

Phase 6: Switch from takeoff to cruise aero data and from takeoff to climb propulsion data. End phase at 6,000 feet.

Phase 7: Use cruise aero and climb thrust propulsion. End phase at 10,000 feet altitude.

Constraints	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7
$2.3° \leq \gamma$ (4% climb gradient)	√	√					
$0° \leq \gamma$			√	√	√	√	√
$0 \leq$ climb rate ≤ 4000 ft/min.	√	√	√	√	√	√	√
$0\% \leq$ throttle $\leq 100\%$	√	√	√	√	√	√	√
V_2+10 kts $\leq V_{cas} \leq 250$ knots	√	√	√	√	√	√	√
$-4°$/sec $\leq$ Pitch Attitude Rate $\leq 4°$/sec	√	√	√	√	√	√	√
$0°$/sec $\leq$ Flap Retraction Rate $\leq 1.4°$/sec	√	√	√				
$\delta_f = 0°$				√	√	√	√
Acceleration ≥ 0			√	√	√	√	√
$\alpha \leq \alpha_{max}(\delta_f)$	√	√	√	√	√		
Mach ≥ 0.3						√	√
Time at Takeoff Power ≤ 5 minutes	√	√	√	√	√		
Noise (if invoked)	√	√	√	√	√	√	√

TABLE 4. - Aircraft Operations at Small/Medium Airport in 1991

Aircraft Type	CLASS	No. of Average daily departures
MD-80	A	13.37
737	A	8.34
737	AA	12.08
737	E	10.31
757	A	11.36
757	AA	16.06
A320	A	5.39
A320	AA	0.15
BA146	E	5.82
Total		82.88

TABLE 5. - Aircraft Operations at Small/Medium Airport in 2015

Aircraft Type	No. of Average daily departures
* MD-90	31.48
* 737-300	81.64
757	61.04
* A320	24.84
Total	199.00

* Potential for performance benefit when replaced with "noise sized" aircraft with advanced high lift systems

TABLE 6. - Aircraft Operations at a Large Airport in 1991 and 2015

	ICAO GENERIC AIRCRAFT TYPE	PNYA 1991 FLEET MIX	(5 A/C TYPE) 1991 FLEET MIX	(6 A/C TYPE) 1991 FLEET MIX	PNYA 2015 FLEET MIX	(6 A/C TYPE) 2015 FLEET MIX
CONCRD	SS	5.58	5.58	5.58		
74710Q	5	80.52	149.54	74.77		
747200	5	12.56				
74720B	5	7.02				
DC1010	5	43.72		74.77		
DC1030	5	5.70				
747400	5				227.11	227.11
MD11	5	0.02			208.60	208.60
A300	4	43.08	126.88			
L10115	4	38.5			5.87	
747SP	4	2.9			87.60	
767JT9	4	3.78			11.33	
767CF6	4	38.62		126.88	98.50	203.30
A310	3	30.24	56.22	56.22	66.50	
757RR	3	25.98			52.84	
757PW	3				201.20	320.54
727200	2	98.96	191.76	191.76		
727Q15	2	4.46				
727100	2	4.18				
707320	2	2.00				
707	2	3.64				
MD82	2	15.46				
F28MK4	2	1.54				
DC860	2	10.92				
DC870	2	3.30				
DC950	2	5.92				
DC850	2	6.00				
CVR580	2	1.72			3.50	
GIIB	2	0.16			0.27	
MD83	2	6.78			31.43	
MD90	2				43.48	136.07
737300	2	4.90			9.94	
7373B2	2	1.26			23.48	
737QN	2	20.56			20.83	
BAE146	2				3.14	
DHC7	1	96.36	178.94	178.94	6.70	363.42
DHC8	1	9.62			1.56	
BEC58P	1	3.40			162.59	
CNA500	1	0.78			52.91	
SF340	1	6.78			13.76	
HS748A	1	0.12			0.12	
MU3001	1	0.02			0.02	
LEAR35	1	0.28			0.58	
SD330	1	61.58			125.18	

TABLE 7. - Performance Factors of Noise Sized Aircraft With Advanced High Lift Systems

Short-to-Medium Range Aircraft at Maximum Range, 70%PL, 800' Cutback			
Altitude, ft	DFBR Ratio	Speed Ratio	Thrust Ratio
0	1.00	1.00	0.88
0	1.07	0.97	0.89
35	1.06	0.96	0.89
800	1.06	0.98	0.89
801	1.06	0.98	0.96
3000	1.01	0.98	0.96
3001	1.01	0.98	0.89
5000	1.06	1.00	0.89
7503	1.09	1.00	0.88

Short-to-Medium Range Aircraft at Maximum Range, 70%PL, 1500' Cutback			
Altitude, ft	DFBR Ratio	Speed Ratio	Thrust Ratio
0	1.00	1.00	0.88
0	1.07	0.97	0.89
35	1.06	0.96	0.89
1000	1.07	0.98	0.89
1500	1.09	0.98	0.89
1501	1.09	0.98	0.96
3000	1.02	0.98	0.96
3001	1.02	0.98	0.89
5000	1.08	1.00	0.88

Medium-to-Long Range Aircraft at Maximum Range, 70%PL, 1500' Cutback			
Altitude, ft	DFBR Ratio	Speed Ratio	Thrust Ratio
0	1.00	1.00	0.90
0	1.07	0.98	0.91
35	1.05	0.97	0.91
1000	1.02	0.98	0.91
1500	1.04	0.98	0.91
1501	1.04	0.98	0.94
3000	1.01	0.98	0.94
3001	1.01	0.98	0.91
6000	1.06	1.00	0.91

TABLE 8. - Certification and Contour Comparison for Short-to-Medium Range Aircraft

150 PAX CERTIFICATION LEVELS, EPNdB	HBPR, Conv H/L	HBPR, Adv H/L	VHBPR, Conv H/L	VHBPR, Adv H/L
SIDELINE	91.9	90.8	84.0	83.3
CUTBACK	86.5	87.0	77.4	77.8
APPROACH	97.2	95.1	89.6	89.3
EPNL CONTOUR AREA, sq. mi.				
85	7.655	5.794	2.200	2.063
90	2.983	2.576	1.072	1.047
95	1.453	1.272	.694	.706
100	.823	.792	.554	.570
SEL CONTOUR AREA, sq. mi.				
85	4.295	3.329	1.621	1.458
90	2.110	1.781	.815	.798
95	.931	.850	.580	.597
100	.621	.607	.494	.505

TABLE 9. - Certification and Contour Comparison for Medium-to-Long Range Aircraft

275 PAX CERTIFICATION LEVELS, EPNdB	HBPR, Conv H/L	HBPR, Adv H/L	VHBPR, Conv H/L	VHBPR, Adv H/L
SIDELINE	98.0	97.5	88.1	87.4
CUTBACK	95.8	96.4	85.7	86.2
APPROACH	104.9	103.2	96.4	96.0
EPNL CONTOUR AREA, sq. mi.				
85	27.468	24.612	4.721	4.511
90	12.312	10.821	2.577	2.536
95	4.370	4.020	1.649	1.639
100	2.397	2.224	1.139	1.152
SEL CONTOUR AREA, sq. mi.				
85	20.751	18.941	3.723	3.156
90	6.955	6.318	2.029	1.857
95	2.861	2.572	1.284	1.247
100	1.743	1.676	.986	1.012

TABLE 10. - Reduced Payload and Range Effects on Community Noise

150 PAX, HBPR CERTIFICATION LEVELS, Δ EPNdB	500 NM 800' c/b	500 NM 1500' c/b	1500 NM 800' c/b	1500 NM 1500' c/b	2500 NM 800' c/b	2500 NM 1500' c/b
SIDELINE	1.4	1.4	1.4	1.4	1.2	1.2
CUTBACK	.9	1.1	.9	1.1	.3	.3
APPROACH	2.1	2.1	2.1	2.1	2.1	2.1
EPNL CONTOUR AREA CHANGE, %						
85	30%	29%	30%	32%	22%	23%
90	19%	10%	21%	11%	15%	5%
95	18%	18%	18%	18%	17%	15%
100	10%	12%	10%	11%	8%	8%
SEL CONTOUR AREA CHANGE, %						
85	35%	27%	35%	34%	23%	22%
90	21%	12%	24%	13%	19%	7%
95	13%	17%	13%	16%	12%	13%
100	9%	9%	8%	8%	6%	6%

TABLE 11. - Noise Benefit of Noise Sized Aircraft With Advanced High Lift Systems

Maximum Range, 70% LF	MD-90 Base	MD-90 Noise Sized	MD-11 Base	MD-11 Noise Sized	747 Base	747 Noise Sized
CERTIFICATION LEVELS, EPNdB						
SIDELINE	91.8	90.6	94.8	93.4	99.2	98.0
CUTBACK	93.2	91.1	98.2	97.4	102.1	101.1
APPROACH	93.1	91.8	102.0	100.5	104.1	101.1
EPNL CONTOUR AREA, sq. mi.						
85	6.99	5.14	11.70	10.01	25.05	21.30
90	3.02	2.10	6.43	5.76	12.08	10.21
95	1.22	.79	3.95	3.56	6.56	5.44
100	.53	.37	2.56	2.38	3.58	3.10
SEL CONTOUR AREA, sq. mi.						
85	3.62	2.98	8.44	7.46	16.30	13.89
90	1.48	1.14	4.56	4.07	7.84	6.64
95	.72	.53	2.79	2.56	4.05	3.44
100	.34	.29	1.94	1.85	2.42	2.25

Maximum Range, 70% LF	MD-90 Base	MD-90 Noise Sized	MD-11 Base	MD-11 Noise Sized	747 Base	747 Noise Sized
CERTIFICATION LEVELS, EPNdB						
SIDELINE		1.2		1.4		1.2
CUTBACK		2.1		.8		1.0
APPROACH		1.3		1.5		3.0
EPNL CONTOUR AREA CHANGE, %						
85		26%		14%		15%
90		30%		10%		15%
95		35%		10%		17%
100		30%		7%		13%
SEL CONTOUR AREA CHANGE, %						
85		18%		12%		15%
90		23%		11%		15%
95		26%		8%		15%
100		15%		5%		7%

TABLE 12. - Noise Contours for the Small / Medium Noise Sensitive Airport

	Ldn Contour Area, sq. mi.				
SMALL AIRPORT	55	60	65	70	75
1991	3.63	1.49	0.61	0.33	0.24
1995	4.80	1.87	0.75	0.36	0.26
2005	4.97	2.03	0.81	0.38	0.27
2015	6.29	2.52	1.02	0.45	0.28
2015 (AHL)	5.68	2.29	0.91	0.41	0.28
% ΔArea (2015)	9.7	9.1	10.8	8.9	0.0

TABLE 13. -Noise Contours for the Large Capacity Airport

	Ldn Contour Area, sq. mi.				
LARGE AIRPORT	55	60	65	70	75
1991	143.37	72.65	28.01	11.75	4.95
2005	64.40	24.87	10.33	4.01	1.99
2015	105.76	42.71	17.64	6.85	2.93
2015 (AHL)	96.32	37.36	14.99	5.54	2.55
% ΔArea (2015)	8.9	12.5	15.0	19.1	13.0

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The noise benefit of advanced designs on future aircraft was evaluated for short-to-medium and medium-to-long range aircraft operations at both small/medium size noise sensitive and large capacity airports. A study of advanced flight procedures made possible by incorporation of automated flight systems was also conducted. A modest noise benefit can be realized through "noise sizing" with advanced high lift systems on future aircraft. The single event noise contour area was reduced by 25% for the short-to-medium aircraft. The noise contour of the medium-to-long range aircraft was reduced by 15%. Furthermore, the potential for growth in airport operations due to noise sized aircraft with advanced high lift systems was 10% for a small noise sensitive airport and 20% for a large capacity airport. The OTIS optimization program was used to show that the noise reduction benefit of new aircraft can be maximized by implementing automated flight management and thrust management systems in aircraft. Additional contour area reduction was obtained for the small-to-medium range aircraft with high bypass ratio engines. .

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